U.S. DEPARTMENT OF COMMERCE
National Technical Information Service

PB-256 394

Metals Mining and Milling Process Profiles with Environmental Aspects

Battelle Columbus Labs.

Prepared For
Industrial Environmental Research Lab.

June 1976

239025

PB 256 394

EPA-600/2-76-167
June 1976

Environmental Protection Technology Series

UNITED STATES · ENVIRONMENTAL PROTECTION AGENCY

REPRODUCED BY
NATIONAL TECHNICAL
INFORMATION SERVICE
U. S. DEPARTMENT OF COMMERCE
SPRINGFIELD, VA. 22161

RESEARCH REPORTING SERIES

Research reports of the Office of Research and Development, U.S. Environmental Protection Agency, have been grouped into five series. These five broad categories were established to facilitate further development and application of environmental technology. Elimination of traditional grouping was consciously planned to foster technology transfer and a maximum interface in related fields. The five series are:

1. Environmental Health Effects Research
2. Environmental Protection Technology
3. Ecological Research
4. Environmental Monitoring
5. Socioeconomic Environmental Studies

This report has been assigned to the ENVIRONMENTAL PROTECTION TECHNOLOGY series. This series describes research performed to develop and demonstrate instrumentation, equipment, and methodology to repair or prevent environmental degradation from point and non-point sources of pollution. This work provides the new or improved technology required for the control and treatment of pollution sources to meet environmental quality standards.

EPA REVIEW NOTICE

This report has been reviewed by the U.S. Environmental Protection Agency, and approved for publication. Approval does not signify that the contents necessarily reflect the views and policy of the Agency, nor does mention of trade names or commercial products constitute endorsement or recommendation for use.

This document is available to the public through the National Technical Information Service, Springfield, Virginia 22161.

BEST SELLERS

FROM
NATIONAL
TECHNICAL
INFORMATION
SERVICE

Comparison of Energy Consumption Between West Germany and the United States
PB-245 652/ PAT 112 p. PC$5.50/MF $3.00

A Comprehensive Policy to Ameliorate Adverse Impacts of Transportation Facilities
PB-247 823/ PAT 138 p. PC$6.00/MF $3.00

A Comprehensive Policy to Ameliorate Adverse Impacts of Transporation Facilities, Appendix
PB-247 824/ PAT 310 p. PC$9.75/MF $3.00

Demand for Coal for Electricity Generation 1975–1984
PB-245 216/ PAT 40 p. PC$4.00/MF $3.00

A National Study of Adolescent Drinking Behavior, Attitudes and Correlates
PB-246 002/ PAT 405 p. PC$11.00/MF $3.00

Energy from Coal: Guidelines for the Preparation of Environmental Impact Statements
PB-242 960/ PAT 258 p. PC$9.00/MF $3.00

Energy Versus the Environment: The Issues
PB-246 382/ PAT 35 p. PC$4.00/MF $3.00

Improving the Dissemination of Scientific and Technical Information: A Practitioner's Guide to Innovation
PB-247 057/ PAT 203 p. PC$7.75/MF $3.00

Investigation and Evaluation of Cracking in Austenitic Stainless Steel Piping of Boiling Water Reactor Plants
PB-246 645/ PAT 123 p. PC$5.50/MF $3.00

Pipeline Industry's Practices Using Plastic Pipe in Gas Pipeline Facilities and the Resulting Safety Factors
PB-247 301 / PAT 436 p. PC$11.75/MF $3.00

NOx Combustion Control Methods and Costs for Stationary Sources. Summary Study.
PB-246 750/ PAT 117 p. PC$5.50/MF $3.00

Reactor Safety Study: An Assessment of Accident Risks in U.S. Commercial Nuclear Power Plants
PB-248 200/SET/ PAT 2,504 p. 8 Volumes PC$61.00

Report on Sulfur Oxide Control Technology
PB-246 667/ PAT 89 p. PC$5.00/MF $3.00

Research Evaluation of a System of Natural Air Conditioning
PB-243 498/ PAT 364 p. PC$10.50/MF $3.00

Retrofitting a Residence for Solar Heating and Cooling: The Design and Construction of the System
PB-247 482/ PAT 101 p. PC$5.50/MF $3.00

Saudi Arabia Five-Year Plan, 1975–1980
PB-246 572/ PAT 683 p. PC$16.25/MF $3.00

Shotcrete Practice in Underground Construction
PB-248 765/ PAT 501 p. PC$12.75/MF $3.00

Short-Term Coal Forecast, 1975–1980
PB-247 073/ PAT 120 p. PC$5.50/MF $3.00

State Energy Information Systems: A Survey
PB-247 457/ PAT 64 p. PC$4.50/MF $3.00

A Study of Fixed Capital Requirements of the U.S. Business Economy
PB-248 690/ PAT 84 p. PC$5.00/MF $3.00

Sulfates and the Environment—A Review
PB-248 122/ PAT 155 p. PC$6.75/MF $3.00

HOW TO ORDER

When you indicate the method of payment, please note if a purchase order is not accompanied by payment, you will be billed an addition $5.00 *ship and bill* charge. And please include the card expiration date when using American Express.

Normal delivery time takes three to five weeks. It is vital that you order by number or your order will be manually filled, insuring a delay. You can opt for *airmail delivery* for a $2.00 charge per item. Just check the *Airmail Service* box. If you're really pressed for time, call the NTIS Rush Order Service. (703) 557-4700. For a $10.00 charge per item, your order will be airmailed within 48 hours. Or, you can pick up your order in the Washington Information Center & Bookstore or at our Springfield Operations Center within 24 hours for a $6.00 per item charge.

You may also place your order by telephone or TELEX. The order desk number is (703) 557-4650 and the TELEX number is 89-9405.

Whenever a foreign sales price is NOT specified in the listings, all foreign buyers must add the following charges to each order: $2.50 for each paper copy; $1.50 for each microfiche; and $10.00 for each Published Search.

Thank you for your interest in NTIS. We appreciate your order.

METHOD OF PAYMENT
☐ Charge my NTIS deposit account no.__________
☐ Purchase order no.__________
☐ Check enclosed for $__________
☐ Charge to my American Express Card account number
☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐

Card expiration date__________
Signature__________
☐ Airmail Services requested

NAME__________
ADDRESS__________
CITY, STATE, ZIP__________

Item Number	Quantity		Unit Price*	Total Price*
	Paper Copy (PC)	Microfiche (MF)		

Sub Total	
Additional Charge	
Enter Grand Total	

* All Prices Subject to Change
8/76

Clip and mail to:
NTIS
National Technical Information Service
U.S. DEPARTMENT OF COMMERCE
Springfield, Va. 22161
(703) 557-4650 TELEX 89-9405

TECHNICAL REPORT DATA

(Please read Instructions on the reverse before completing)

1. REPORT NO. EPA-600/2-76-167

2.

3. RECIPIENT'S ACCESSION NO.

4. TITLE AND SUBTITLE Metals Mining and Milling Process Profiles with Environmental Aspects

5. REPORT DATE June 1976

6. PERFORMING ORGANIZATION CODE

7. AUTHOR(S) R.J. Nerkervis and J.B. Hallowell

8. PERFORMING ORGANIZATION REPORT NO.

9. PERFORMING ORGANIZATION NAME AND ADDRESS
Battelle Columbus Laboratories
505 King Avenue
Columbus, Ohio 43201

10. PROGRAM ELEMENT NO. 1AB015; ROAP 21AFH-025

11. CONTRACT/GRANT NO. 68-02-1323, Task 35

12. SPONSORING AGENCY NAME AND ADDRESS
EPA, Office of Research and Development
Industrial Environmental Research Laboratory
Research Triangle Park, NC 27711

13. TYPE OF REPORT AND PERIOD COVERED Task Final; 8/75-5/76

14. SPONSORING AGENCY CODE EPA-ORD

15. SUPPLEMENTARY NOTES IERL-RTP task officer for this report is W.G. Tucker, Mail Drop 63, 919/549-8411, Ext 2745.

16. ABSTRACT The report describes the environmental aspects of metals mining and milling (concentration) operations in the U.S. The metals include Al, Sb, Be, Cu, Au, Fe, Pb, Zn, Hg, Mo, Ni, Pt, the rare earth metals, Ag, Ti, W, U, and V. The types of environmental impacts associated with operations from mining through production of concentrate are described in general terms; the nature of each metal category of the industry is described in terms of number and locations of plants, the names of producing companies, production levels, and other characteristics of the industry. Flowsheets are presented which indicate raw materials inputs, unit operations, and intermediate and final products. Each unit process is described in terms of function, input materials, operating conditions, utilities and energy use, and waste streams. The descriptions of unit processes identify waste streams in terms of emissions to the air, water effluents, and solid wastes disposed to the land. The approximately 185 unit operations described include mining, dredging, crushing, flotation, leaching, sintering, and nodulizing. The most common waste streams are dusts from mining and crushing operations, liquid streams from mine drainage, flotation operations, tailings ponds, and leaching operations.

is presented.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Pollution	Pollution Control	13B
Metals	Stationary Sources	11F, 07B
Metal Industry	Production Levels	05C
Mining		08I
Comminution		13H, 07A
Industrial Processes		

18. DISTRIBUTION STATEMENT Unlimited

19. SECURITY CLASS (This Report) Unclassified

20. SECURITY CLASS (This page) Unclassified

21. NO. OF PAGES 318

22. PRICE 9.75

EPA Form 2220-1 (9-73)

PRICES SUBJECT TO CHANGE

EPA-600/2-76-167
June 1976

METALS MINING AND MILLING PROCESS PROFILES WITH ENVIRONMENTAL ASPECTS

by

R.J. Nerkervis and J.B. Hallowell

Battelle-Columbus Laboratories
505 King Avenue
Columbus, Ohio 43201

Contract No. 68-02-1323, Task 35
ROAP No. 21AFH-025
Program Element No. 1AB015

EPA Task Officer: W.G. Tucker

Industrial Environmental Research Laboratory
Office of Energy, Minerals, and Industry
Research Triangle Park, NC 27711

Prepared for

U.S. ENVIRONMENTAL PROTECTION AGENCY
Office of Research and Development
Washington, DC 20460

METALS MINING AND MILLING PROCESS PROFILES WITH ENVIRONMENTAL ASPECTS

TABLE OF CONTENTS

Page

I. INDUSTRY DESCRIPTION 1

A. Metal Industry Segment Sizes, Major Participating Companies, and Localities. 1

B. Raw Materials and Products 3

C. Environmental Impacts. 7

1. Atmospheric Emissions. 8

a. Open-Pit Mining. 8

b. Underground Mining 9

c. Crushing, Grinding, and Classifying. 9

d. Drying Process-Stream Materials. 9

e. Roasting and Calcining 10

2. Emission of Liquid Wastes. 10

a. Open-Pit Mining. 10

b. Underground Mining 11

c. Placer Mining. 12

d. Crushing and Screening 12

e. Crushing, Grinding, and Classifying. 12

f. Gravity Concentration. 13

g. Flotation. 13

h. Magnetic Concentration 13

i. Leaching 14

j. Solution Extraction. 14

k. Tailings Ponds and Reservoirs. 15

3. Emission of Solid Wastes 15

a. Open-Pit Mining. 17

b. Underground Mining 17

c. Placer Mining. 18

d. Gangue Minerals--Tailings. 18

e. Leach Residues 19

f. Miscellaneous Solid Wastes 19

METALS MINING AND MILLING PROCESS PROFILES
WITH ENVIRONMENTAL ASPECTS

TABLE OF CONTENTS (Cont.)

Page

4. Overview. 19

D. References. 21

II. INDUSTRY ANALYSIS 21

A. Aluminum. 24

B. Antimony. 36

C. Beryllium 44

D. Copper. 57

E. Gold. 96

F. Iron. 129

G. Lead and Zinc 155

H. Mercury 166

I. Molybdenum. 183

J. Nickel. 195

K. Platinum Group Metals 201

L. Rare Earth Metals 205

M. Silver. 215

N. Titanium. 225

O. Tungsten. 240

P. Uranium 252

Q. Vanadium. 270

III. APPENDICES

A. Population of U.S. Metal-Mining and Beneficiation Companies A-1

B. Raw Materials, Minerals, and Products Utilized in Metal-Mining and Milling Industry. B-1

METALS MINING AND MILLING PROCESS PROFILES WITH ENVIRONMENTAL ASPECTS

INDUSTRY DESCRIPTION

U.S. industries engaged in the mining of ores for the production of metals are identified as major group 10 in the Standard Industrial Classification (SIC) Manual, 1972, published by the Executive Office of the President (Office of Management and Budget). This industry category includes establishments engaged in mining ores for the production of metals, and includes all ore dressing and beneficiating operations, whether performed at mills operating in conjunction with the mines or at mills operated separately. These include mills which Crush, grind, wash, dry, sinter, or leach ore, or perform gravity separation or flotation operations.

The industry categories covered by this report include the following:

SIC 1011 - Iron Ores
SIC 1021 - Copper Ores
SIC 1031 - Lead and Zinc Ores
SIC 1041 - Gold Ores
SIC 1044 - Silver Ores
SIC 1051 - Bauxite Ores
SIC 1061 - Ferroalloy Ores
SIC 1092 - Mercury Ores
SIC 1094 - Uranium/Radium/Vanadium Ores
SIC 1099 - Metal Ores, Not Elsewhere Classified.

The various metal values covered in these SIC codes are shown in Table I. Twenty-three categories have been identified as commercially important. Of these, seventeen are analyzed in this report. Two more, thorium and zirconium, occur as byproducts and are analyzed in conjunction with the principal metallic ore. The remaining four, chromium, columbium-tantalum, manganese, and tin are almost wholly imported and thus do not come under the scope of this study.

Metal Industry Segment Sizes, Major Participating Companies, and Localities

Industry segments vary drastically in size. Table I shows the production and consumption data of metal values in the U.S. Iron and steel is by far the largest. Aluminum is second in consumption, lead and

TABLE I. SUMMARY OF PRODUCTION AND CONSUMPTION DATA (U.S. METAL-MINING INDUSTRY PRODUCTION VERSUS TOTAL U.S. METAL CONSUMPTION

Metal	U.S. Ore Production, Millions of Short Tons	U.S. Metal Primary Production From Domestic Ores, Millions of Pounds	U.S. Metal Consumption (all sources) Millions of Pounds	U.S. Metal Production/Consumption Ratio, %
Aluminum	2.07	1,040.00	15,600.00	~ 7
Antimony	no data	1.30	79.00	1 to 2
Beryllium	no data	~ 0.50	0.624	80
Columbium-Tantalum	no data	--	4.00	--
Copper	280	3,600.00	6,800.00	~ 53(a)
Gold	6.6	0.089	0.524	17
Iron	209	120,000.00	180,000.00	66
Lead	~ 10	1,510.00	3,100.00	~ 49
Zinc	~ 10	1,000.00	3,040.00	~ 33
Manganese	0.23	60.00	3,800.00	1 to 2
Mercury	0.08	0.904	4.060	22
Molybdenum	20	112.00	57.00	196
Nickel	--	30.00	390.00	7 to 8
Platinum	no data	~ 0.001(b)	0.116	~ 1
Rare earths	no data	27.40	27.40	100
Silver	~ 1	3.117	15.417	20
Thorium	no data	--	0.300	--
Tin	no data	0.220	124.00	< 1
Titanium Oxide	~ 25	1,540.00	1,674.00	92
Titanium	none	--	42.00	0(c)
Tungsten	0.74	3.50	7.75	45
Uranium Oxide(d)	~ 7	28.00	24.00	117
Vanadium	no data	--	10.60	--
Zirconium	none	--	6.00	0(c)
Zircon	no data	250.00	380.00	66

(a) Copper from secondary recovery would increase this ratio to about 95 percent.
(b) About 1,164 pounds.
(c) All ore for metal production was imported.
(d) Production and consumption on a U_3O_8 basis.

zinc are next (the consumption of manganese is slightly larger than lead and zinc, but 98 percent of manganese ore is imported). Titanium oxide and zircon account for considerable domestic tonnage production. The only other metal produced in amounts in excess of 45.4 million kilograms (100 million pounds) annually in the U.S. is molybdenum.

There are currently about 200 readily identifiable companies in the U.S. participating in the recovery and beneficiation of ores for metal production. It is estimated that there may be as many as 100 to 150 additional companies that are small and/or are operating intermittently, or that participate less directly in ore recovery (e.g., exploration and construction, excavation, and transportation companies). The number of major participating companies for each of the metal segments of the industry (again on the basis of the primary metal production) are given in Table II. Selected prominent company names are included in this table, whereas more complete listing of participating companies is given in Appendix A. Figure I is a map of the continental United States dipicting the approximate locations of the major metal-mining operations. There are approximately 250 mining sites shown which account for the bulk of the U.S. production.

Raw Materials and Products

The major raw material in a metal-mining and beneficiating operation is, of course, the ore body. An ore body is a mineral deposit which, under current economic and technological conditions, can be exploited for the recovery of its valuable minerals at a possible profit. Usually, there is a dominant mineral or an assemblage of minerals of a dominant metal in an ore body, although the importance of coproduct and/or byproduct metals cannot be overstated. "Mine evaluation, process selection, in fact, ore deposit economics leading to decisions to open a mine can be ultimately based on the presence and recoverability of byproduct metals."* Thus, as shown in Table III, several metals are apt to be the target of operations at a single site in the U.S. practice. The basic raw material is nevertheless the mineral or minerals for a dominant metal. Table I in Appendix B lists the ore deposit names and the principal minerals being mined in the U.S. for the metals of SIC 10 included in this study. The names of the beneficiated products resulting from U.S. mining operations also are given in Table I, Appendix B.

In addition to the ore deposit as the principal raw material for a mining operation, there are usually a host of other materials required. For example, blasting materials (explosives) are used in most mining operations. Drilling and loading equipment requires fuel and lubricants, and, in numerous cases, wooden timbers and other construction materials are used in mine support, as well as in building mine entrance, access, and equipment storage structures. The equipment for mined ore transport requires fuel and lubricants.

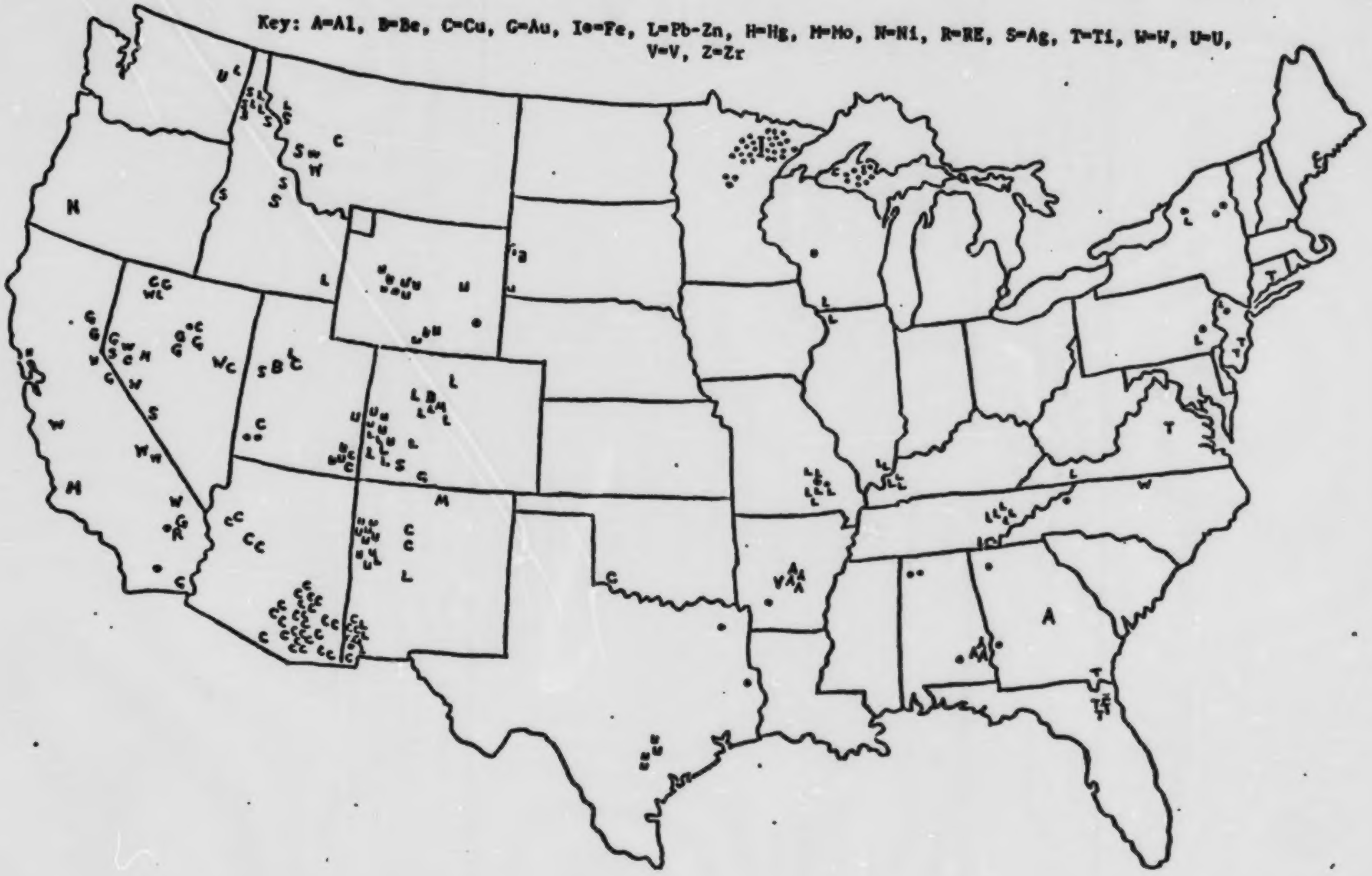
---

* Mr. Edward R. Bingham, Manager, Environmental Affairs, Copper Range Company, Michigan

TABLE II. THE NUMBER OF READILY IDENTIFIABLE COMPANIES PARTICIPATING IN THE U.S. METAL ORE PRODUCTION

Metal	Symbol used in Figure 1	Number of Participating Companies (a)	Selected Company Names (b)
Aluminum	A	10	Alcoa, Reynolds
Antimony	--	2	Hecla, Sunshine
Beryllium	B	5	Brush Wellman, Berylco
Columbium-Tantalum	--	(1)	(Byproduct production) Curtis Nevada Corp.
Copper	C	32	Anaconda, Cities Service, Kennecott, Hecla, U.V.
Gold	G	12	Carlin, Homestake, U.V. Industries
Iron	I or *	35	Cities Service, Cleveland Cliffs, Hanna, U.S. Steel
Lead-Zinc	L	28	AMAX, Bunker Hill, Kennecott, St.Joe, N.J. Zinc
Managanese	--	(3)	(Byproduct production) Hanna, N.J. Zinc
Mercury	H	4-5	All very small companies (Placer Amex Co. start up in 1975) (c)
Molybdenum	M	2	Climax Molybdenum (Div AMAX), Molycorp.
Nickel	N	1	Hanna Mining Company
Platinum	--	1	Goodnews Bay Mining Co. (Alaska)
Rare Earths	R	2	Molycorp, Curtis Nevada Corp.
Silver	S	14	Bunker Hill, Hecla, Sierra Silver-Lead, Sunshine
Thorium	--	(5)	(Byproduct production) Humphreys Eng., du Pont
Tin	--	(1)	(Byproduct production) Climax-Molybdenum (Div AMAX)
Titanium	T	7	Glidden-Durkee, Humphreys Eng., du Pont, N.L. Industries
Tungsten	W	10	General Electric, Mines Exploration, Rawhide, U.C.
Uranium	U	24	Anaconda, Atlas, Exxon, Kerr-McGee, Ranchers, U.C.
Vanadium	V	1	U.C. (i.e., (Union Carbide)
Zirconium	Z	(3)	(Byproduct production) Humphries, du Pont

(a) Readily identifiable major participating companies
(b) See Chapters VII through XXVII for complete names and locations
(c) Large and new producer.



Key: A=Al, B=Be, C=Cu, G=Au, I=Fe, L=Pb-Zn, H=Hg, M=Mo, N=Ni, R=RE, S=Ag, T=Ti, W=W, U=U, V=V, Z=Zr

FIGURE I. LOCATION OF THE PRINCIPAL METAL-MINING ACTIVITIES IN THE CONTINENTAL UNITED STATES

TABLE III. CLASSIFICATION OF SELECTED METALS MINED IN THE UNITED STATES

Group A Principally Single Metal Production		Group B Metals Mined as Principal, Coproduct or Byproduct Values		Group C Metals Mined only as Coproduct or Byproduct Values	
Aluminum	Al(a)	Copper	Cu(d)	Columbium	Cb (Ta)
Beryllium	Be	Antimony	Sb	Manganese	Mn
Boron	B	Gold	Au	Radium	Ra(e)
Magnesium	Mg	Iron	Fe(d)	Tin	Sn
Mercury	Hg(b)	Lead	Pb(d)	Thorium	Th
Nickel	Ni	Molybdenum	Mo(d)	Zirconium	Zr
Silicon	Si	Platinum Group	Pt		
Iron	Fe(c)	Rare-Earth Group	RE		
		Silver	Ag		
		Titanium	Ti(d)		
		Tungsten	W		
		Uranium	U(d)		
		Vanadium	V		
		Zinc	Zn(d)		

(a) Some byproduct gallium.
(b) Coproduct gold from some ore. Byproduct mercury from some zinc ores.
(c) Coproduct manganese or titanium from some ores.
(d) These elements might be considered as subgroup B-1, metals commonly mined as principal value, balance as subgroup B-2, metals seldom mined as principal value.
(e) Not currently recovered for resale.

Beneficiation operations take their share of raw materials too, ranging from simply the fuel to run sizing equipment to a host of materials required for the more sophisticated physical and chemical separations. Various conditioning chemicals such as zinc sulfate, lime, sodium sulfide, zanthates, phosphates, oils, and flocculating agents are used. Table II in Appendix B summarizes the raw materials used in mining and beneficiation and includes typical flotation reagents.

A very important raw material consumed in many beneficiation operations is steel, particularly that used in grinding. For example, the copper segment uses about 0.75 kg (1.5 lb) of steel in grinding balls and vessel liner per metric ton (short ton) of ore. This amounts to over 181,400 metric tons (200,000 short tons) of steel per year for just the copper segment of the industry. In cost, this can equal the cost of flotation reagents. Steel consumed in grinding, crushing, drilling, and loading operations is a significant raw material expendable.

Another raw material, water, is used at the rate of 4 tons per ton of ore in copper beneficiating. While maximum possible recycle of water is practiced, water consumption via evaporation loss, etc., is also a significant raw material expendable.

The products of the U.S. metal-mining industry as indicated in Table I in Appendix B may range from a metallic product (e.g., mercury and crude gold bullion) to a run-of-mine ore (e.g., a rich iron ore), or to lean ore concentrate. Beneficiation operations of some type are currently used in every U.S. mine to supply a product which is suitable for subsequent ore reduction and metal-winning operations. The concentrates can vary in their value content from low (e.g., 11 percent BeO in a beryl concentrate) to high (e.g., crude gold from retorting an amalgamated concentrate). Further, a concentrate product may contain several metals which will not be separated one from the other until a later processing step which is not a part of the beneficiation process. On the other hand, some beneficiation operations achieve a separation of mineral species as an integral part of the concentrating operation.

Environmental Impacts

The U.S. metal-mining and beneficiating industry handles a large volume of a variety of materials, mostly rock, in a wide range of process steps. Emissions from the materials and processes can be a problem. In addition to emissions, other types of environmental disruptions are associated with mining and beneficiation activities. The general characteristics of emissions and environmental problems of the industry are described in this section.

The raw materials and processing steps which constitute the core of the mining and beneficiating industry are described in detail in the individual metal-industry segment flowsheets. Generally, emissions from similar processing steps in the various segments of the industry are essentially the same from one segment of the industry to another. Therefore, the arrangement of the process descriptions in this section is presented in a manner to serve for all segments having common process steps. Atypical emissions from common process steps are noted in the individual industry process descriptions where variations in materials or processes lead to uncommon conditions. Also, for industrial segments utilizing uncommon process steps, descriptions of emissions from such steps are noted in the process descriptions.

Atmospheric Emissions - Emissions from the mining and beneficiating processes to the atmosphere may consist of either or both particulate and gaseous materials, some of which may be hazardous to health. The physical nature and the chemical composition of the atmospheric emissions depend to some extent on the segment of the industry from which the emissions are derived. On the other hand, the commonality of emissions from the various process steps that are common to several segments is great and these characteristics are described in the following subsections.

Open-Pit Mining. Some portion of the atmospheric emissions from this process step comes from the consumption of fuel providing energy for the mining equipment. Drilling and loading equipment, as well as auxiliary transport equipment, contribute to the total emissions.

Explosives and their abundant use in blasting operations associated with open-pit mining contribute to atmospheric emissions. Hydrocarbons may be used as explosives extenders. Commonly, ammonium nitrate is also used in conjunction with primary explosives for maximum ore breakage per unit of explosive. For example, up to one-sixth kilogram of explosive per metric ton (one-third pound of explosive per short ton) of ore is used in a typical pit mining operation. Generally, the explosives emissions are the oxides of nitrogen of several species. While not an emmission per se and therefore not elsewhere described in this report, the environmental disturbance of blasting noise may be a problem under particular circumstances.

Many open-pit mining operations are conducted under dry conditions, essentially year round in semiarid districts, and periodically in the dry seasons of wetter climates. Dust as an emission to the atmosphere commonly occurs, and a universal range for its occurrence on a quantitative basis is 0.25 to 0.51 kilograms per metric ton (0.5 to 1.02 pounds per short ton) of ore. It is not a problem in the open-pit mining of naturally wet ores (e.g., nickel ores at Riddle, Oregon), and it can be controlled to some extent by water spraying under the drier operating conditions. In some operations, the ore is of such a nature that it does not readily dust even under dry conditions.

Underground Mining. Fumes from fuel consumption in mining equipment operation contribute to the atmospheric emissions from underground mining. No quantitative data are available to indicate compositions and quantities of fumes attributable to this source. However, it is known that there are oxides of nitrogen in underground mine fumes from the use of explosives. Fumes or gases also might emanate from the mining operation per se in the form of hydrocarbons (e.g., methane) sulfides (e.g., H_2S), and others. Radon gas is a problem in some underground uranium mining operations. All of the mine gas is brought to the surface via the ventilating systems and may be dispersed to the atmosphere without good control. The average particulate content of ventilated underground mine gas discharges is 0.05 kilograms of dust per metric ton (0.1 pound of dust per short ton) of ore mined. The particulates are generally large and may be precipitated in the vicinity of the mining activity.

Crushing, Grinding, and Classifying. Crushing as an initial process step in preparing mined ore for additional beneficiation can give rise to large quantities of dust to the atmosphere. [The emission factor for crushing is up to 3.75 kilograms of particulates per metric ton (7.5 pounds of particulates per short ton) of ore.] Quantities of dust generated in this step may vary with rock type and moisture content of the ore. Crushing is usually followed by grinding. Both rod mills and ball mills may be used in grinding with both types usually being operated wet in closed circuits with classifiers. Classifiers are of various types which send various size ranges of crushed and ground ore on to different circuits. For example, oversize material might be recycled or discarded, properly sized material might be sent on to the next process step, and undersize material might be sent to a special materials handling circuit. If accomplished as a wet operation in a closed system, there is no dust problem. If it is a dry system, dust emissions to the atmosphere from screening can be high [e.g., 38 kilograms per metric ton of feed (76 pounds per short ton) of feed] but controllable (e.g., via baghouses). Further, the grinding of rocks, either wet or dry, can result in the release of rock gases of various species and these may be vented to the atmosphere.

Drying Process-Stream Materials. Several process steps used in beneficiating metal ores are accomplished in water slurries and, in other cases, precipitates are obtained from aqueous solutions. Frequently, such wet processing requires further processing in the dry state and for this the process-stream material or the precipitate must be dewatered and dried. Cyclone equipment, drum filters, etc., may be used to dewater with the possibility of producing liquid waste effluents. The dewatered pulp or precipitate may be dried in ovens, rotary furnaces, multiple-hearth furnaces, etc. Emissions to the atmosphere from drying usually consist of only water vapor and coarse particulates (in contrast to reaction products such as gases, fume, etc.). The emissions are generally amenable to control by standard control techniques, i.e., hot precipitators, baghouses, or, less likely, wet scrubbers.

Roasting and Calcining. Process-stream material may be reduced or chemically altered in the presence of another added material (e.g., salt roasting) or oxidized and/or fritted or physically altered in form by heating (e.g., calcining). These so-called roasting or calcining steps involve a high energy input to the ore. Furnaces of various types are used. Both fumes and particulates may be released to the atmosphere. For example, in roasting operations, emissions to the atmosphere may contain fuel combustion products from natural gas, oil, coke, or coal, and reaction products such as the gasses CO_x, SO_x, H_2S, NO_x, etc. Particulate emissions will include not only the coarse particles lost from the process material but also so called fume, characterizable as particulates which are chemical reaction products condensed from the gas phase--submicron metal oxides, for example. Emissions of this kind may be controlled by the use of electrostatic precipitators, baghouses, or wet scrubbers. The recovery of discharge material from roasting or calcining process steps may be required to prevent unacceptable metal losses which would otherwise occur (e.g., in the case of nickel ore processing).

Emission of Liquid Wastes - Natural water is frequently encountered in mining operations and it may become contaminated with mine chemicals. Also, large quantities of water are used in processing metal ores. As cited previously, about 4 kg of water are used per kg of ore in some segments. Wastewaters containing very large levels of suspended (e.g., asbestiform gangue minerals) and dissolved (e.g., cyanide salts) solids may be produced. The composition of these emissions often may be unique to particular locales or to particular metal segments of the industry. However, there is a commonality of liquid waste emissions from several process steps which is described in the following subsections.

Open-Pit Mining. The major effluent problem associated with open-pit mining is acid mine drainage. The disturbed rock of some ore deposits, their overburden, and the surrounding country rock may give up chemicals to the natural water drainage system of the locale. For example, sulfide minerals of many species, but most commonly pyrites (iron sulfides), may be exposed in open-pit mining with the result of sulfidizing (i.e., acidifying) the drainage waters. Control of this kind of emission may be nonexistent or extensive. An example of the latter is the 45,000,000 liters per day (12,000,000 gals/day) lime and settling water treatment plant in operation at one bauxite mine. Under proper operating conditions, the acid discharge to the local water system is negligible. In semiarid localities, the problem may be nonexistent owing to lack of water and essentially no drainage.

The inescapable operational factors which must be recognized here are the magnitude of the volumes of overburden and ore which are moved. The stripping of overburden, exposing oxidizable minerals to the air, often results in waste piles of a size approaching major features of the terrain (i.e., mountains) and the depth of the pits may well involve cutting through one or more natural aquifiers. Thus, control of natural runoff water (rain) or the pumping of mine water necessary to maintain working conditions at the lower level of the pit involve considerations on the scale of miles or handling the entire output of an aquifier. A recent example of such an exercise was completed in an open-pit copper mine in Arizona where expansion of the pit into new areas of the ore body involved the diversion of a natural water course including a sizable dam and the cutting of a 2.4 kilometer (1-1/2 mile) tunnel.

In addition to water contamination by rock chemicals due to earth disturbance, there is the possibility of wastes being emitted to the water from other materials. For example, fuel and oil spills or discharges are a possibility. Also, explosives contribute a high nitrogen discharge to the drainage waters which can result in downstream algae blooms, etc.

Underground Mining. Underground mining operations may give rise to an acid mine drainage problem also. The layout of some mines in their topographical setting may allow a natural drainage to lower slopes and, in some cases, ground water from higher slopes might actually percolate through the ore before exiting at lower slopes. In wet mines where natural drainage is inadequate, mine waters are pumped to the surface. The minerals of the ore body and the country rock may give up soluble constituents to the waters. Sulfides are undoubtedly the most frequent problem. The acidity of discharge waters can be quite high. Control is always difficult and expensive especially in cases of high-volume discharge.

The volumes and nature of mine water are always unique to the individual underground mine. Mine water may vary in nature from high quality drinking water to highly silted (high suspended solids) water with chemical characteristics varying from acid to alkaline, depending on the mineral and/or rock matrix. The use of explosives, an absolute requirement in hard-rock underground mining, contributes to a high nitrogen content of the discharge mine waters.

Placer Mining. There are various methods of placer mining and all require copious quantities of water. Depending largely on the nature of the deposit, hydraulic methods (pressure streams and sluicing), dredges, or other techniques might be used. Deposits can range from stream-bed gravels to bank-run silts that might be remote from present stream or beach. Dredges might work entirely within an existing water body or a working pool might be created which migrates with the pace of mining. The major emission problem that is usually associated with placer mining is the silting of discharge waters. Fuel spills may contribute to the liquid waste problem. If blasting is used (e.g., it is used in southern Georgia titanium placer mining operation), it may contribute to a high nitrogen discharge to adjacent waters. Exposure of previously buried rock formations may result in oxidation and erosion of otherwise stable rock formations. Another environmental problem that can be associated with placer mining of stream deposits is channelization of the stream bed--potentially damaging in itself to the native ecology of the stream.

Crushing and Screening. Crushing operations are usually a dry process and may or may not require and have dust control equipment in association. If wet scrubbers are used to control particulate emissions, the scrubber water may be included in the plant water system, usually passing through the tailings pond before recycle. The water burden from the scrubbers may discharge in the tailings pond and from the pond may discharge to the local area drainage--in due course.

Screening and washing operations (if screening is accomplished wet) similarly may use water from the plant system and discharge some portion of the mined ore to the tailings pond. Commonly, silts, clays, and undersize ore fractions are separated from the desired ore fraction and are discharged to the waste water system.

Crushing, Grinding, and Classifying. Usually, water is introduced in the grinding operation of the beneficiation system, and acts as a vehicle for the transport of ground ore. Conditioning chemicals may be added, even in the grinding step. Unwanted ore fractions (e.g., clays) may be separated in the classifiers and discharged via the water system to the tailings pond. The waters thus may carry a waste emissions burden which may or may not be controlled in the pond.

Gravity Concentration. Most gravity concentrating systems are operated as wet processing steps utilizing water as the ore carrier. Additives such as heavy media compounds (e.g., ferrosilicon) may be used to facilitate the separation functions of this concentrating method. In many wet gravity concentrating systems, closed circuits are utilized wherein the gravity equipment is in series with another concentrator such as flotation cells. In other gravity systems, only gravity concentration is used to separate the value minerals from the gangue, discharging the gangue tailings to the reservoir pond. Here the tailings may be discharged and the conditioned water recirculated. In operations located near large bodies of water, tailings water may not be recycled. Thus, there are two possible liquid waste emission problems: one associated with tailings pond water control and the other with discharge of waters contaminated on a once-through basis.

Flotation. The flotation concentrating method requires large volumes of water which is conditioned with a variety of chemical compounds to achieve the ore particle float-no float phenomena. Examples of the chemicals used are given in Table II in Appendix B, and these are added to serve the functions of dispersant, collector, promoter, frother, and flocculant in the flotation process step. Usually, there are several banks of flotation cells in a rougher concentrating, cleaner, and recleaner sequence. Separations of value minerals from gangue and of one type value mineral from another are achievable in essentially closed systems. However, gangues are carried to and discharged in ponds. Dewatering systems (e.g., cyclone thickeners or filters) in the circuit may thicken the discard routed to the pond and overflows of substantially clear water (altered with residuals of the additives previously mentioned) may be recirculated. Needless to say, the tailings ponds receive an adulterated water burdened with suspended solids and dissolved materials and the control of this waste from flotation systems is required.

Magnetic Concentration. This concentrating-separating method may be accomplished either in the wet or dry state, on either belt- or drum-type equipment, and either singly or in combination with other concentrating equipment. Wet magnetic concentrating systems always have the potential of adding a waste rock burden to the water vehicle, even in cases where both fractions of the magnetic separation are to be subsequently processed in additional steps. Water soluble constituents of the ore and gange minerals to be discarded are the burden carried to the water reservoir of the system. Discharge of the burden in the pond facilitated by chemical treatment in some cases and by physical means (settling) permits water recycle. The process step has an emissions potential which may require careful control in some cases.

Leaching. The specific liquid wastes obtained from the various metal ore leaching processes are described in the individual metal segment flowsheets. Several types of leaching media are used, depending on the ore. For example, water leaching is used to extract vanadium, acid leaching (sulfuric) for copper, salt solution (sodium cyanide) for gold, and alkali (carbonate) for uranium. In each case, leaching solutions are carefully guarded against loss since they contain the value mineral. Nevertheless, accidental spills of leach liquors are possible, particularly in cases where large volumes of liquid are involved and spills may mean liquid waste emissions to the local drainage system or ground waters.

In addition to spills, spent leaching solutions may be discharged to holding reservoirs. The solutions may become inefficient due to the buildup of various salts, in which case they may be ponded for rejuvenation or for eventual discard. More commonly, pregnant leach liquors (solutions loaded with the value metal) are stripped of their values by operations such as the cementation process step for copper or the solution extraction process step of the type used for several metals. Stripped leaching solutions also may be ponded for recycling. In all cases, the ponded liquors require control to prevent the inadvertent discharge of the liquid waste to the surrounding environment.

The principal problems with leach liquors are identifiable as spills when incurred under such circumstances as ruptures in cross-country pipelines, washouts of dikes or dams by flood, or, in one case, overflow during a labor strike. Elaborate surveillance, spill control, and containment safety measures are necessary precautions.

Solution Extraction. Leach liquors may be stripped of their mineral values in a solution extraction process step. These operations consist of mixing the pregnant leach liquor with an organic liquid which preferentially and sometimes quantitatively removes the value metal ion from the leach liquor with simultaneous dissolution in the organic. The solutions may be separated in settling tanks. The spent leach liquor is known as the raffinate and may be discharged as described in the preceding section on leaching. In a few cases, the raffinate may contain another value metal from leaching, selectively rejected by the first organic solution (e.g., vanadium from uranium solutions), and is further processed to collect the second value. Quite often the raffinate contains only very small amounts of residual values, but may contain a large burden of waste materials. Thus, control of raffinates to prevent liquid waste emission to the environment is essential.

The mixing of leach liquor and organic solution in the extraction circuit is followed by remixing of the organic with a stripping solution. The value metal goes to the stripping solution preferentially; in effect it is the reverse of the extraction circuit. The stripping solution may be small in volume to achieve maximum concentration. Precipitation from the stripping solution is accomplished either by adjustment of pH or by addition of other chemicals. The organic solutions are high priced and the stripping solutions carry the value metal. Therefore, great care is taken not to have losses in either. Nevertheless, the possibility of spills exists and these must be considered in the total picture for liquid waste emissions.

Tailings Ponds and Reservoirs. Tailings ponds are frequently used as one of the storage reservoirs in plant water recirculation practice, but, more importantly, they are used as the sink for the sedimentation of solids emanating from the total operation. As described in preceding sections, scrubber water, equipment cooling water, and water from the various beneficiation process steps (e.g., flotation, leaching raffinate) as well as excess mine water and possibly sanitary system water may pass to the tailings pond. Particulate, colloidal, and soluble wastes might therefore be present, and the control of such mixtures is essential. The treatment of water for quality improvement prior to discharge is frequently practiced. However, inadequate water treatment and wet season overflow discharges may permit the wastes to be carried to area streams.

The tailings ponds associated with large flotation concentration operations are one of the outstanding characteristics of the mining industry. They are invariably large [hectares to hundreds of hectares (acres to hundreds of acres)]. Depending on climate and plant capacity, the tailings pond may serve as a major water treating and conservation device or as the major apparent source of water discharge. For example, in the arid southwestern states, all water is usually discharged to the tailings pond, and because of long retention times which lead to a good degree of water quality, the tailings pond then serves as a source of a large fraction of process water.

In climates with a positive net annual accumulation of rainfall, discharges from the tailings pond are necessary. The quality of the discharge water varies with the individual operation. In some cases, economical treatment is a problem because of the large volume involved.

Emission of Solid Wastes - Voluminous solid wastes are generated in the metal-mining industry. The most recent published statistics on the quantities of waste materials generated by metal-mining operations are indicated in Table IV. This information is compiled annually by the Bureau

TABLE IV. MATERIAL HANDLED AT SURFACE AND UNDERGROUND MINES, BY COMMODITY, IN 1972

(Thousand Short Tons)

Commodity	Surface			Underground			All Mines		
	Crude Ore	Waste	Total(a)	Crude Ore	Waste	Total(a)	Crude Ore	Waste	Total
Aluminum	2,560(b)	9,230(b)	11,800(b)	W(c)	W	W	2,560(b)	9,230	11,800
Copper	237,000	683,000	920,000	34,700	685	35,400	271,000	684,000	955,000
Gold	4,870	16,106	20,930	1,700	219	1,910	6,560	16,306	22,930
Iron Ore	197,000	167,000	364,000	11,600	1,310	12,900	209,000	168,000	377,000
Lead	-	102	102	9,560	452	10,000	9,560	554	10,100
Mercury	51	53	105	30	3	34	82	57	138
Silver	69	32	100	588	160	749	657	192	849
Titanium	26,100	823	27,000	-	-	-	26,100	823	27,000
Tungsten	8	52	60	734	130	864	741	182	923
Uranium	3,800	171,000	175,000	2,690	654	3,350	6,450	172,000	178,000
Zinc	19	-	19	8,180	948	9,130	8,210	948	9,150
Other(d)	19,400	32,300	51,600	15,800	562	16,300	35,200	32,900	68,000
Total metals(a)	491,000	1,080,000	1,570,000	85,700	5,120	90,800	576,000	1,080,000	1,660,000

(a) Data may not add to totals shown because of independent rounding.
(b) Includes underground; the Bureau of Mines is not at liberty to publish separately.
(c) W Withheld to avoid disclosing individual company confidential data, included with "Surface".
(d) Antimony, beryllium, magnesium, manganese, molybdenum, nickel, platinum group metals, rare-earth metals, tin, and vanadium.

of Mines, and does not include in the waste column the wastes from concentrating operations, i.e., only mining wastes are reflected in the table. The tailings from the crude ore, after extraction of the value minerals, will constitute a waste quantity in addition to the wastes given in the table.

The composition of the solid waste from the industry is dependent on the characteristic rock types, as well as on other raw material additions. In general, the solids are not toxic, but may be hazardous to health in other respects, as is the case of asbestiform minerals. They may also become a source for toxic emissions as they weather and otherwise alter with time to give up undesirable chemicals.

Open-Pit Mining. Literally, mountains of overburden material may be removed in open-pit mining prior to achieving access to the ore body. Stripping techniques and efficiencies have so greatly improved that up to tens to hundreds of meters (hundreds of feet) of overburden may be removed. The waste material is stored in heaps adjacent to the pits for possible restoration to the pit at some later time.

Once the ore body is exposed, it may be exploited directly with all subsequent blasting and loading, or as in numerous cases, it may require selective mining to separate ore from waste rock and rich ore from lean ore. Waste country rock can amount to very large tonnages. For example, the estimate for the waste rock in the open-pit being developed by Climax Molybdenum, Colorado, is 236 million metric tons (260 million short tons). Since the ore reserve being opened is estimated at 168 million metric tons (185 million short tons), the waste-to-ore ratio is 1.4 to 1. The waste rock will, of course, be added to the waste heaps.

The problems with rock heaps range from unsightliness through disruptions of wildlife habitat, to being a source of toxic materials to the air and water as the rocks weather and alter chemically with time.

Underground Mining. There is typically less waste rock associated with underground mining than with open-pit mining for several reasons. First, little or no overburden need be removed prior to development of shaft or adit. Secondly, ores mined by underground methods are necessarily richer to support the higher cost of underground mining. Further, massive excavation of barren country rock is avoided wherever possible because of the expense and because a limited passageway from one ore pocket to the next is quite sufficient for ore access. Nevertheless, the quantities of waste mine rock generated can be very large for some underground operations and these accumulate in waste rock storage heaps at some minimum distance from the mine.

Placer Mining. The solid waste rock emission for placer mining is probably less than for either open-pit or underground mining. However, large quantities of relatively unconsolidated detrital rock are usually displaced in placer mining. The spoil banks of disturbed rock may be replaced fairly easily in some workings. In other cases, the spoil banks remain as a disturbing blight on the landscape, marking in perpetuity the path of the dredges. Apart from the unsightliness of these solid waste heaps, the heaps may contribute to the ravages of a stream caused by channelization, and, as heap material may be redistributed in floodtime, the entire character of a water body may be altered by the loosened and redistributed material.

Gangue Minerals--Tailings. The ore minerals in a deposit may constitute a very small percentage of the ore body, or, as in the case of aluminum ore (bauxite), may comprise almost the total amount mined. The worthless portion of the mined ore is eliminated in numerous beneficiation process steps, and is variously referred to as gangue, tails, tailings, waste, and waste rock.

The first cut or separation of gangue from value minerals may occur in the first screening or the first washing process step. Thereafter, many of the process steps can result in a tail or a residue consisting principally of gangue, which is routed to solid waste disposal sites. Most frequently, this site is the tailings pond. Very large quantities of gangue or tailings may accumulate from the beneficiation steps. The process steps usually contributing to solid waste emissions of this type include the following:

Screening
Washing
Classifying
Gravity concentrating
Flotation concentrating
Magnetic concentrating
Electrostatic concentrating
Solid-liquid separation processes
  (e.g., filtering).

These are not the only process steps wherein the worthless material is separated. Solid waste also is produced in the various leaching processes. In addition, tailings may contain a variety of noxious chemicals with the potential of giving up these compounds to the environment.

Leach Residues. Residues from the various leaching practices contribute to the solid wastes associated with metal mining and beneficiation. Tank or vat leaching leaves a washed residue which may be stored in dumps and is capable of emitting compounds to the environment during storage. Heap leaching may entail less washing after leaching due to the giant size of the heap and other factors. Consequently, leached heaps may constitute solid waste environmental problems not only due to their bulk but as well to their residual acid, cyanide, and other possibly noxious chemical constituent.

Miscellaneous Solid Wastes. Residues from thermal operations such as retorting may consist of gangue and other process materials which may be disposed of as solid waste. The material may be leached prior to discard. Residues from mercury furnacing operations may be simply dumped. Other solid waste disposal problems may be associated with such items as spent resins from ion exchange separation processing steps, junk accumulation in plant operation, and sanitation wastes.

Overview - The following listing briefly summarizes the unit process operations and the emissions discussed in this section. The listing is arranged to show the relationship of emissions to unit process.

- Open-pit Mining
    - Equipment engine exhausts
    - Blasting emissions
    - Digging and transport dusts
    - Run-off water
    - Mine water
    - Overburden and waste mine rock
        - Dusting of waste heaps
        - Waste heap run-off
- Underground Mining
    - Ventilation air--dust and possible mine gases
    - Mine water
    - Waste mine rock
        - Dusting
        - Run-off water

Crushing

  Dust

Screening

  Dust

Grinding

  Dust (if performed dry)

Flotation Concentration

  Tailings Slurry

    Water containing flotation reagents
    Suspended solids (tailings)

Gravity Separations

  Water containing conditioning chemicals
  Suspended solids (tailings)
  Heavy media residuals

Tailings Ponds

  Dusting from dry portions
  Water outfalls--suspended and dissolved solids
  Tailings

Leaching

  Acid, alkali, and/or solvent spills
  Leach residues (tailings)
  Run-off water from residues

Drying, calcining, roasting, and retorting

  Gases containing particulates, dust, fume, vapors or gaseous reaction products
  Solid residue (in the case of retorting or roasting of volatile metals).

References

The following references are general references. Specific references for the processes covered in the flowsheet are provided at the end of each flowsheet.

(1) Wood, R. A.; Hallowell, J. B.; and Cherry, R. H. Jr.; Demonstration Opportunities in the U.S. Metals-Mining Industry, Battelle-Columbus Laboratories to Environmental Protection Agency, Control Systems Laboratory, Contract 68-02-1323, Task No. 15, December 31, 1974.

(2) Hallowell, J. B., et al., Water Pollution Control in the Primary Nonferrous Metals Industry, Vol. II, Aluminum, Mercury, Gold, Silver, Molybdenum, and Tungsten, Battelle-Columbus Laboratories to Office of Research and Monitoring, U.S. Environmental Protection Agency, EPA R2-73-247b, September, 1973.

(3) Private communication with members of the Battelle-Columbus staff and with metal industry representatives on energy usage in U.S. metal mining and beneficiation.

(4) Calspan Corporation Development Document for Effluent Limitations Guidelines and Standards of Performance to U.S. EPA Office of Water and Hazardous Materials, Effluent Guideline Division, Contract No. 68-01-2682, April, 1975.

(5) Staff, Bureau of Mines, Mineral Facts and Problems, 1970, Bureau of Mines Bulletin 650, Bureau of Mines, U.S. Department of the Interior.

(6) Staff, Bureau of Mines, Mineral Facts and Problems, 1965, Bureau of Mines, U.S. Department of the Interior.

INDUSTRY ANALYSIS

Flowsheets covering process descriptions of the following segments of the metal-mining and ore-dressing industries are covered in this report.

Aluminum
Antimony
Beryllium
Copper

Gold
Iron
Lead and zinc
Mercury
Molybdenum
Nickel
Platinum Group Metals
Rare Earth Metals
Silver
Titanium
Tungsten
Uranium
Vanadium.

As indicated earlier, six of the 23 industry segments are not covered by individual flowsheets because either the U.S. is completely dependent on foreign sources for the particular metal or metallic ore or it is a by-product and is covered in the flowsheet for the principal metallic ore. The six segments of the industry which fall into these two categories are as follow:

Chromium - The U.S. is completely dependent on foreign sources for chromite, the only commercial source of chromium. No chromite has been mined in the United States since 1961.

Columbium (Niobium)-Tantalum - There is virtually no U.S. production of ores of these metals. Very small amounts are produced from a single California mine as a by-product with noble and rare earth metals.

Manganese - The U.S. is almost completely dependent on imports for its manganese; 98 percent is imported, 2 percent is obtained from secondary manganese and from manganiferous iron ores charged to the blast furnace.

Thorium - U.S. thorium production (about 150 metric tons per year) is almost entirely as a by-product from the rare-earth containing mineral monazite, itself a by-product of U.S. east coast titanium and Colorado molybdenum minerals production. Small amounts are also obtained as a by-product from Alaskan uranium ore. Thorium by-product production is covered in the flowsheets covering these principal ore values.

Tin - The U.S. is wholly dependent on foreign sources for tin (imports amounted to 55,000 metric tons in 1973). About 100 metric tons are produced each year as a by-product of primary molybdenum recovery in Colorado.

Zirconium - Zircon ($ZrSiO_4$), the principal mineral source of zirconium is recovered as a by-product in the mining of titanium and monazite minerals in beach sand deposits. This is covered in the titanium segment. Waste characteristics and water uses accompanying mining and milling to obtain zircon concentrate are identical to those for titanium minerals.

Raw materials (ores) and products for these metal segments which are not covered individually in flowsheets are shown in Appendix A with the names of companies producing the metal or associated product.

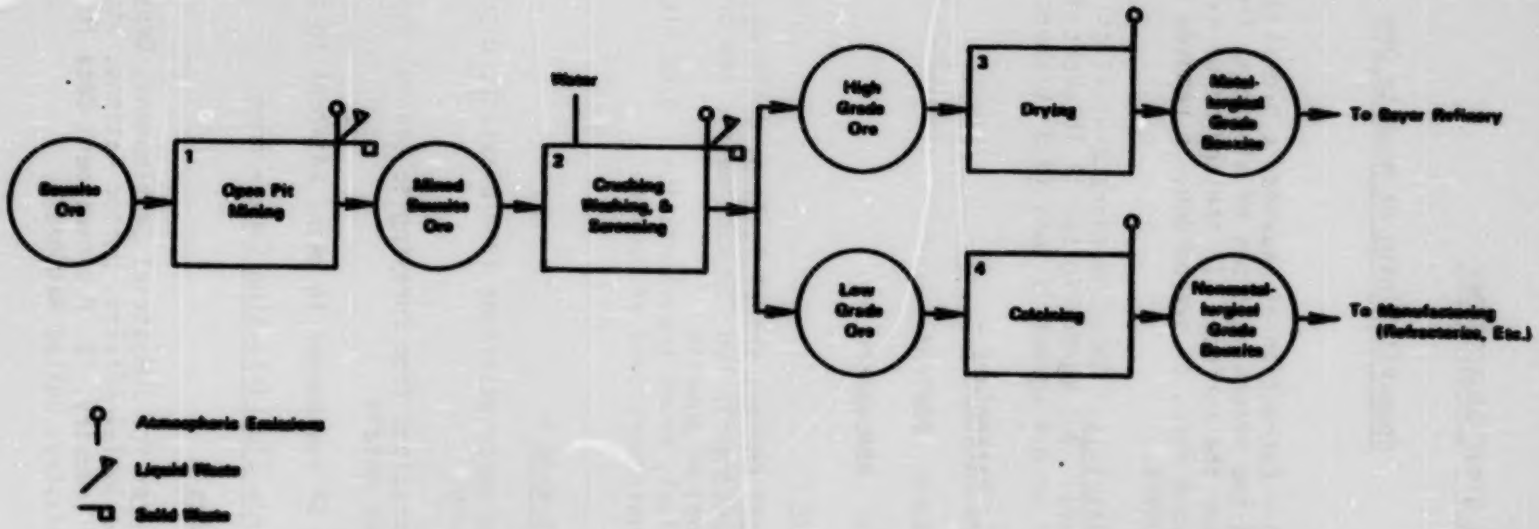
The flowsheets of metals mined and beneficiated in the U.S. are arranged alphabetically as in the listing above. The flowsheets contain process descriptions of the various industry segments. Subdivisions in processing steps have been made where emissions to the environment are significant. Type of emissions--gaseous, liquid waste, and solid waste--are indicated by appropriate flags (see flowsheets) placed on the isolated processing steps. Input materials and products are shown enclosed in circles, processing steps are shown in enclosed boxes. Information provided in the flowsheets includes a description of the function of the processing step, specific details on materials, input and output, operating parameters, energy expenditure of utilities per ton of ore processed, and details of emissions and waste streams from each processing unit. The EPA Source Classification is given if it exists, and references from which details of operation were obtained are provided at the end of each process flowsheet.

Aluminum

While the United States is a large consumer of the world production of aluminum, a very small amount of the ore for aluminum production, bauxite, is mined domestically. Over 90 percent of our domestic aluminum production is based on bauxite imported from foreign mining and beneficiating operations. The U.S. bauxite production is about 2 million short tons (2.07 million tons in 1973 which was about 7 percent of our bauxite requirements) whereas the world production of bauxite is approximately 78 million short tons.

The silica content and the form in which it is present in a bauxite ore body are important factors in the yield of a bauxite ore. On a molar basis, two parts of silica tie up one part of alumina in the mineral kaolinite $Al_2O_3.2SiO_2.2H_2O$. The silica content results in the consumption of caustic solution in the formation of insoluble sodium aluminum silicate in refining operations. (The use of high-silica bauxites involves excess reagent losses or the use of a two-step, "combination" process to recover the losses in the initial processing.) In some operations in the U.S., kaolin is a coproduct of bauxite production and the bauxite itself may be capable of beneficiation only to a nonmetallurgical grade (for example, for ultimate use in refractories or abrasives rather than for metal production). Metallurgical grade bauxite ore is produced in the U.S., however, notably from the Arkansas deposits.

Aluminum


Bauxite Ore
1
Open Pit Mining
Mined Bauxite Ore
Water
2
Crushing Washing, & Screening
High Grade Ore
Low Grade Ore
3
Drying
4
Calcining
Metallurgical Grade Bauxite
Nonmetallurgical Grade Bauxite
To Bayer Refinery
To Manufacturing (Refractories, Etc.)
Atmospheric Emissions
Liquid Waste
Solid Waste

Open-Pit Mining of Bauxite Ore

1. Function - Extraction of bauxite, a hydrated aluminum oxide which is the predominant ore of aluminum, from an ore body lying near the surface. In the course of extraction, overlying waste rock, or overburden, is removed up to thicknesses of 50 meters.

2. Input Materials - Ammonium nitrate--fuel oil slurry explosives: 0.1 kg/metric ton (1 lb/short ton) of material or 0.4 kg/metric tons (0.3 lb/short tons) of bauxite ore.

3. Operating Parameters -

   Temperature: Ambient

   Pressure: Atmosphere

4. Utilities -

   Electrical Energy, shovel loading, drilling, etc: 1.91 x 10^{8} joules/metric ton (53 kWhe/metric ton or 0.51 x 10^{6} Btu/short ton) of bauxite
   Diesel fuel, truck transportation: 0.68 liters/metric ton (0.163 gal/short ton) of bauxite

5. Waste Streams -

   Dust and vapor emissions from blasting, digging, and loading operations

   Water emissions from spraying to control dust, mine drainage, sometimes acidic

   Storage of overburden in heaps adjacent to pits

6. EPA Source Classification Code - None

7. References -

   (1) Center for Industrial Development, Department of Economic and Social Affairs, United Nations, Studies in Economics of Industry, "2. Preinvestment Data for the Aluminum Industry, United Nations".

(2) Chapman, Peter F., "The Energy Cost of Producing Copper and Aluminum from Primary Sources", Open University Energy Research Group Report, No. ERG 001, August 1973, (revised December 1973).

(3) Farin, Philip, Associate Editor, "Aluminum, Profile of the Industry", Metals Week, McGraw-Hill, Inc., 1969.

(4) Bulletin 650, "Mineral Facts and Problems, Aluminum", 1970, Bureau of Mines, U.S. Department of the Interior, pp 437-462.

Crushing, Washing, and Screening

1. Function - Bauxite is crushed to a uniform size. The size produced varies with the hardness of the bauxite ore. The crushed ore is passed over washing screens to remove clay and silica.

2. Input Materials - Bauxite ore and water

3. Operating Parameters -

   Temperature: Ambient

   Pressure: Atmospheric

4. Utilities -

   Electric energy, crushing, and screening: 2.12×10^8 joules/metric ton (59 kWhe/metric ton or 0.56×10^6 Btu/short ton) bauxite
   Electric energy, pumping: 1.08×10^8 joules/metric ton (30 kWhe/metric ton or 0.29×10^6 Btu/short ton) bauxite

5. Waste Streams -

   Dust emissions from crushing and conveyors

   Water emissions from washing

   Clay and silica waste from washing and screening operation

6. EPA Source Classification Code - None

7. References -

   (1) Center for Industrial Development, Department of Economic and Social Affairs, United Nations, Studies in Economics of Industry, "2. Preinvestment Data for the Aluminum Industry, United Nations".

   (2) Chapman, Peter F., "The Energy Cost of Producing Copper and Aluminum from Primary Sources", Open University Energy Research Group Report, No. ERG 001, August 1973, (revised December 1973).

(3) Farin, Philip, Associate Editor, "Aluminum, Profile of the Industry", Metals Week, McGraw-Hill, Inc., 1969.

(4) Bulletin 650, "Mineral Facts and Problems, Aluminum", 1970, Bureau of Mines, U.S. Department of the Interior, pp 437-462.

ALUMINUM - HIGH GRADE BAUXITE ORE PROCESS NO. 3

Drying

1. **Function** - Removal of excess moisture (5 to 25 percent) from crude bauxite to reduce weight and shipping charges. (In some instances, drying is unnecessary.)

2. **Input Materials** - Crude bauxite

3. **Operating Parameters** -

   Temperatures: up to 400 C (752 F). (Temperatures in the upper range are sometimes used to destroy organic materials and improve the digestion rate.)

   Pressure: Atmospheric

4. **Utilities** -

   Natural gas (or heavy oil) for drying: $(0.14\text{-}3.4) \times 10^8$ joules/metric ton [3.8-94 kWhe/metric ton $(0.036\text{-}0.90) \times 10^6$ Btu/short ton] bauxite

5. **Waste Streams** -

   Dust emissions, combustion products

6. **EPA Source Classification Code** - None

7. **References** -

(1) Center for Industrial Development, Department of Economic and Social Affairs, United Nations, Studies in Economics of Industry, "2. Preinvestment Data for the Aluminum Industry, United Nations".

(2) Bielfelt, K; Kampf, F.; and Winkhaus, G.; "Heat Consumption in the Production of Aluminum", Paper No. A75-58, Preprint of paper given at the 104th AIME Annual Meeting, Americana Hotel, New York, N.Y., February 18, 1975.

(3) Farin, Philip, Associate Editor, "Aluminum, Profile of the Industry", Metals Week, McGraw-Hill, Inc., 1969.

(4) Bulletin 650, "Mineral Facts and Problems, Aluminum", 1970, Bureau of Mines, U.S. Department of the Interior, pp 437-462.

ALUMINUM - LOW GRADE BAUXITE ORE PROCESS NO. 1

Open-Pit Mining of Low Grade Bauxite Ore

1. Function - Extraction of nonmetallurgical grades of bauxite ore body near the surface for further processing into calcined bauxite for use in the abrasives and refractory industries.

2. Input Materials - Ammonium nitrate--fuel oil slurry explosives: 0.1 kg/metric ton (.2 lb/short tons) or 0.4 kg/metric ton (0.8 lb/short tons) of bauxite ore.

3. Operating Parameters -

   Temperature: Ambient

   Pressure: Atmospheric

4. Utilities -

   Electrical energy, shovel loading, drilling, etc.: 1.91×10^8 joules/metric ton (53 kWhe/metric ton or 0.51×10^6 Btu/short ton) bauxite.

   Diesel fuel, truck transportation: 1.62×10^8 joules/metric ton (45 kWhe/metric ton or 0.43×10^6 Btu/short ton) bauxite

5. Waste Streams -

   Dust and vapor emissions from blasting, digging, and loading operations

   Water emissions from spraying to control dust, mine drainage, sometimes acidic

   Storage of overburden in heaps adjacent to pits

6. EPA Source Classification Code - None

7. References -

   (1) Center for Industrial Development, Department of Economic and Social Affairs, United Nations, Studies in Economics of Industry, "2. Preinvestment Data for the Aluminum Industry, United Nations".

(2) Kirk-Othmer Chemical Encyclopedia, Aluminum Compouds, Vol 2, 1963 Edition, pp 56-57.

(3) Farin, Philip, Associate Editor, "Aluminum, Profile of the Industry", Metals Week, McGraw-Hill, Inc., 1969.

(4) Bulletin 650, "Mineral Facts and Problems, Aluminum", 1970, Bureau of Mines, U.S. Department of the Interior, pp 437-462.

Crushing, Washing, and Screening

1. Function - Bauxite is crushed to a uniform size. The size produced varies with the hardness of the bauxite ore. The crushed ore is passed over washing screens to remove clay and silica.

2. Input Materials - Bauxite ore and water

3. Operating Parameters -

   Temperature: Ambient

   Pressure: Atmospheric

4. Utilities -

   Electric energy, crushing, and screening: 2.12×10^8 joules/metric ton (59 kWhe/metric ton or 0.56×10^6 Btu/short ton) bauxite

   Electric energy, pumping: 1.08×10^8 joules/metric ton (30 kWhe/metric ton or 300,000 Btu/short ton) bauxite

5. Waste Streams -

   Dust emissions from crushing and conveyors

   Water emissions from washing

   Clay and silica waste from washing and screening operation

6. EPA Source Classification Code - None

7. References -

(1) Center for Industrial Development, Department of Economic and Social Affairs, United Nations, Studies in Economics of Industry, "2. Preinvestment Data for the Aluminum Industry, United Nations".

(2) Kirk-Othmer Chemical Encyclopedia, Aluminum Compounds, Vol 2, 1963 Edition, pp 56-57

(3) Farin, Philip, Associate Editor, "Aluminum, Profile of the Industry", Metals Week, McGraw-Hill, Inc., 1969.

(4) Bulletin 650, "Mineral Facts and Problems, Aluminum", 1970,
Bureau of Mines, U.S. Department of the Interior, pp 437-462.

ALUMINUM - LOW GRADE BAUXITE ORE **PROCESS NO. 3**

Calcining

1. Function - The chemically combined water in the nonmetallurgical grades of bauxite must be removed prior to processing it into brown fused alumina in an electric arc furnace. Normally, a prior drying step is unnecessary unless the calcining plant is at a considerable distance from the crushing, washing, and screening plant.

2. Input Materials - Washed and screened low grade bauxite

3. Operating Parameters -

   Temperature: 930-1600 C (1700-2900 F) for 1-1/2 hr, depending on use

   Pressure: Atmospheric

4. Utilities -

   Natural gas or heavy oil: (24.6-41.6) x 10^8 joules/metric ton [(683-1160) kWhe/metric ton or (6.5-11) x 10^6 Btu/short ton] of feed

5. Waste Streams -

   Dust emissions, combustion products

6. EPA Source Classification Code - None

7. References -

   (1) Center for Industrial Development, Department of Economic and Social Affairs, United Nations, Studies in Economics of Industry, "2. Preinvestment Data for the Aluminum Industry, United Nations".

   (2) Kirk-Othmer Chemical Encyclopedia, Aluminum Compounds, Vol 2, 1963 Edition, pp 56-57.

   (3) Farin, Philip, Associate Editor, "Aluminum, Profile of the Industry", Metals Week, McGraw-Hill, Inc., 1969.

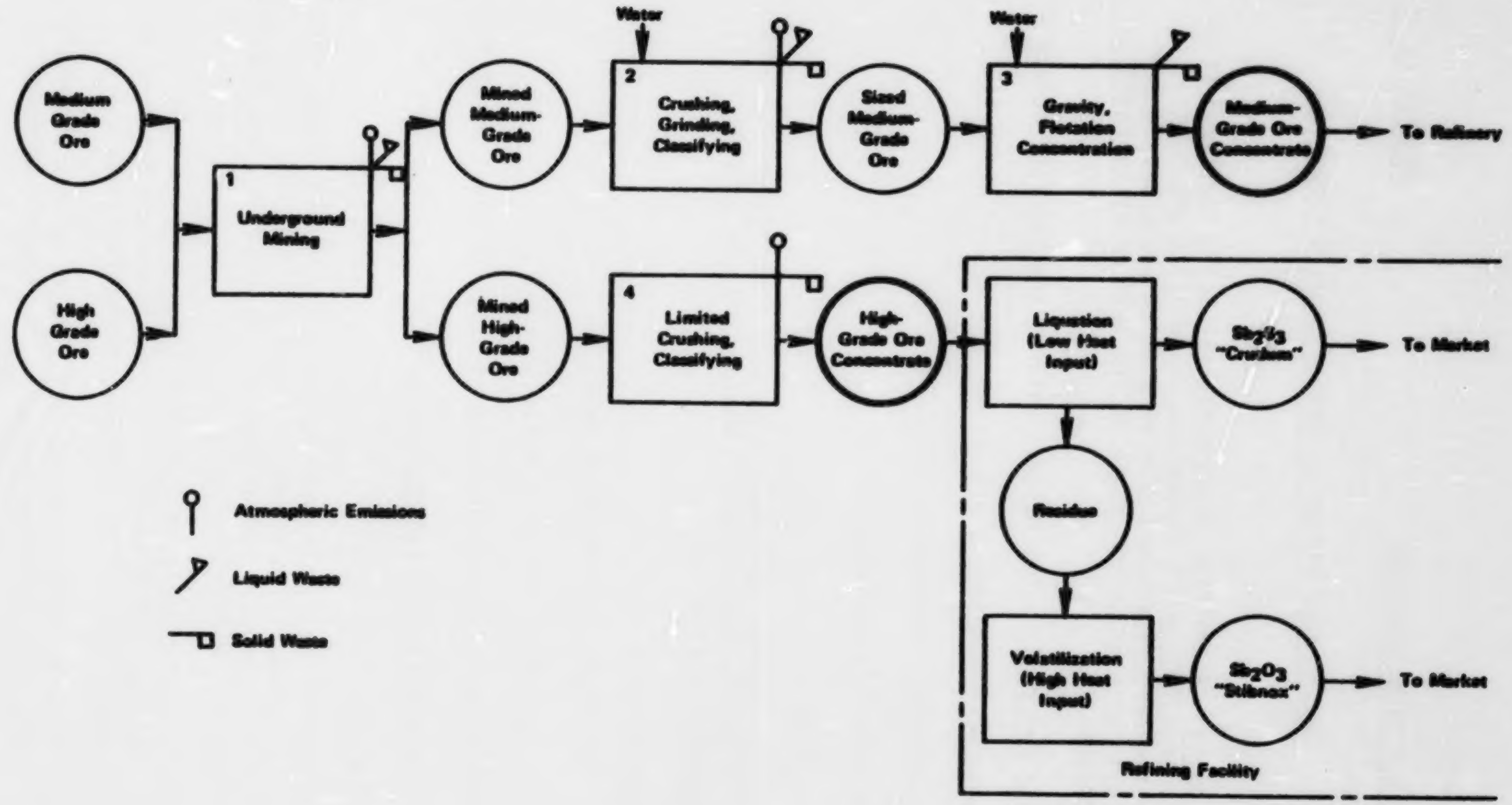
   (4) Bulletin 650, "Mineral Facts and Problems, Aluminum", 1970, Bureau of Mines, U.S. Department of the Interior, pp 437-462.

Antimony

Only about 2 percent of our domestic antimony requirements are generated from U.S. mining operations and the bulk of this is produced as by-product antimony from complex Idaho ores (see Lead Segment). Limited information is available on a new Montana mine under development for the production of antimony (apparently principally for antimony) and the same is the case for small "one-man" prospecting and mining operations that develop intermittently in the western and northwestern states (e.g., Nevada small tonnage operation).

The products from the antimony mining and beneficiating segments of the industry are appropriately named grades of ore concentrate, for example, high-grade or low-grade concentrate. Refinery products resulting from liquation or volatilization operations are commonly named "Crude", "Crudum", or "Needle" (melted and solidified Sb_2S_3) and "Stibnox" (volatilized and condensed Sb_2O_3) from the respective operations. The refining operations are currently seldom if ever used as a part of the beneficiating process.

Antimony



Medium Grade Ore
High Grade Ore
1 Underground Mining
Mined Medium-Grade Ore
Mined High-Grade Ore
Water
2 Crushing, Grinding, Classifying
Sized Medium-Grade Ore
Water
3 Gravity, Flotation Concentration
Medium-Grade Ore Concentrate
To Refinery
4 Limited Crushing, Classifying
High-Grade Ore Concentrate
Liquation (Low Heat Input)
Sb_2S_3 "Crudum"
To Market
Residue
Volatilization (High Heat Input)
Sb_2O_3 "Stibnox"
To Market
Refining Facility
Atmospheric Emissions
Liquid Waste
Solid Waste

ANTIMONY - MEDIUM GRADE ORE

PROCESS NO. 1

Underground Mining of Medium Grade Antimony Ore

1. Function - Extraction of stibnite (Sb_2S_3) or oxidized stibnite ores from small discontinuous deposits which are entered through a short adit or shallow shaft and removed by sill cutting in the plane of the vein or by overhead stoping.

2. Input Materials - Explosives: nitroglycerine derivatives

3. Operating Parameters -

   Temperature: Ambient

   Pressure: Atmospheric

4. Utilities -

   Electric energy, drilling, hoisting, pumping, etc.: 1.80×10^8 joules/metric ton (50 kWhe/metric ton or 0.48×10^6 Btu/short ton) of ore.

5. Waste Streams -

   Air emissions from shaft or adit

   Water emissions from mine pumps

   Storage of waste rock in heaps adjacent to shaft or adit

6. EPA Source Classification Code - None

7. References -

(1) Paone, James, Chapter on Antimony; Mineral Facts and Problems 1970, Bureau of Mines Bulletin 650, Bureau of Mines, U.S. Department of the Interior, Washington, D.C., pp 463-478.

(2) Wyche, Charlie, Preprint of Chapter on Antimony, Vol 1 of the 1970 Minerals Yearbook, Bureau of Mines, U.S. Department of the Interior, Washington, D.C., 9 p.

(3) Private communications with members of the BCL staff who have consulted producers on energy requirements.

Crushing, Grinding, and Classifying

1. Function - Medium grade antimony ores are frequently crushed, ground, and classified to a sufficient degree of fineness to affect a separation of particles of the mineral stibnite (Sb_2S_3) from particles of gangue in subsequent beneficiation processes. In some cases, the ore, after being hand-cobbed, is smelted directly.

2. Input Materials - Broken medium grade antimony ore delivered to the shaft house crusher bins in mine skips.

3. Operating Parameters -

   Temperature: Ambient

   Pressure: Atmospheric

4. Utilities -

   Electric energy: 7.92×10^8 joules/metric ton (220 kWhe/metric ton or 2.1×10^6 Btu/short ton) of ore.

5. Waste Streams -

   Dust emissions from crushers and conveyors

   Water emissions from classifiers

   Solid waste from gangue discard

6. EPA Source Classification Code - None

7. References -

(1) Paone, James, Chapter on Antimony; Mineral Facts and Problems 1970, Bureau of Mines Bulletin 650, Bureau of Mines, U.S. Department of the Interior, Washington, D.C., pp 463-478.

(2) Wyche, Charlie, Preprint of Chapter on Antimony, Vol 1 of the 1970 Minerals Yearbook, Bureau of Mines, U.S. Department of the Interior, Washington, D.C., 9 p.

(3) Private communications with members of the BCL staff who have consulted producers on energy requirements.

ANTIMONY - MEDIUM GRADE ORE **PROCESS NO. 3**

Gravity Concentration, Flotation

1. **Function** - Medium and low grade antimony ores are concentrated by ore-dressing methods in only some cases; oxide ores may be concentrated by jigging; stibnite (Sb_2S_3) ores by flotation (which separates out associated arsenic minerals). Concentration by such means, particularly gravity concentration, has the disadvantage of high slime loss; hence, medium grade ores are often smelted directly, and low grade ores volitilized to produce antimony oxide, removing arsenic in the process because its oxide is more volitile.

2. **Input Materials** - Crushed and ground antimony ore

3. **Operating Parameters** -

   Temperature: Ambient

   Pressure: Atmospheric

4. **Utilities** -

   Jigs, flotation machines, pumps, etc: 3.78×10^8 joules/metric ton (77 kWhe/metric ton or 0.73 Btu/short ton) of ore.

5. **Waste Streams** -

   Water emission from jigs and flotation processing

   Solid waste from tailings discharged from jigs and flotation machines

6. **EPA Source Classification Code** - None

7. **References** -

   (1) Paone, James, Chapter on Antimony; Mineral Facts and Problems 1970, Bureau of Mines Bulletin 650, Bureau of Mines, U.S. Department of the Interior, Washington, D.C., pp 463-478.

   (2) Wyche, Charlie, Preprint of Chapter on Antimony, Vol 1 of the 1970 Minerals Yearbook, Bureau of Mines, U.S. Department of the Interior, Washington, D.C., 9 p.

(3) Private communications with members of the BCL staff who have consulted producers on energy requirements.

(4) Kellog, H. H., "Energy Consumption in Flotation Beneficiation", (unpublished) Columbia University, New York, N.Y., July 1973.

ANTIMONY - HIGH GRADE ORE **PROCESS NO. 1**

Underground Mining of High Grade Antimony Ore

1. Function - Extraction of stibnite (Sb_2S_3) or oxidized stibnite ores from small discontinuous deposits which are entered through a short adit or shallow shaft and removed by sill cutting in the plane of the vein or by overhead stoping.

2. Input Materials - Explosives: nitroglycerine derivatives

3. Operating Parameters -

   Temperature: Ambient

   Pressure: Atmospheric

4. Utilities -

   Electric energy, drilling, hoisting, pumping, etc: 1.80×10^8 joules/metric ton (50 kWhe/metric ton or 0.48×10^6 Btu/short ton) of ore.

5. Waste Streams -

   Air emissions from shaft or adit

   Water emissions from mine pumps

   Storage of waste rock in heaps adjacent to shaft or adit

6. EPA Source Classification Code - None

7. References -

(1) Paone, James, Chapter on Antimony; Mineral Facts and Problems 1970, Bureau of Mines Bulletin 650, Bureau of Mines, U.S. Department of the Interior, Washington, D.C., pp 463-478.

(2) Wyche, Charlie, Preprint of Chapter on Antimony, Vol 1 of the 1970 Minerals Yearbook, Bureau of Mines, U.S. Department of the Interior, Washington, D.C., 9 p.

(3) Private communications with members of the BCL staff who have consulted producers on energy requirements.

Limited Crushing and Classifying

1. Function - Owing to the extreme friability of stibnite (Sb_2S_3), concentration by wet means of ground high grade (45-60 percent antimony) ores entails prohibitively high slime losses. Accordingly, high grade antimony ores receive only a limited amount of crushing. Concentration to increase the stibnite (Sb_2S_3; 71.5 percent antimony) in high grade ores is usually by liquation, and sometimes by precipitation by iron from molten antimony sulfide.

2. Input Materials - Crushed ore

3. Operating Parameters -

   Temperature: Ambient

   Pressure: Atmospheric

4. Utilities -

   Crushers, conveyors: 0.79×10^8 joules/metric ton (22 kWhe/metric ton or 0.21×10^6 Btu/short ton) of ore.

5. Waste Streams -

   Dust emissions from crushers and conveyors

   Solid waste from hand-cobbing procedures

6. EPA Source Classification Code - None

7. References -

   (1) Paone, James, Chapter on Antimony; Mineral Facts and Problems 1970, Bureau of Mines Bulletin 650, Bureau of Mines, U.S. Department of the Interior, Washington, D.C., pp 463-478.

   (2) Wyche, Charlie, Preprint of Chapter on Antimony, Vol 1 of the 1970 Minerals Yearbook, Bureau of Mines, U.S. Department of the Interior, Washington, D.C., 9 p.

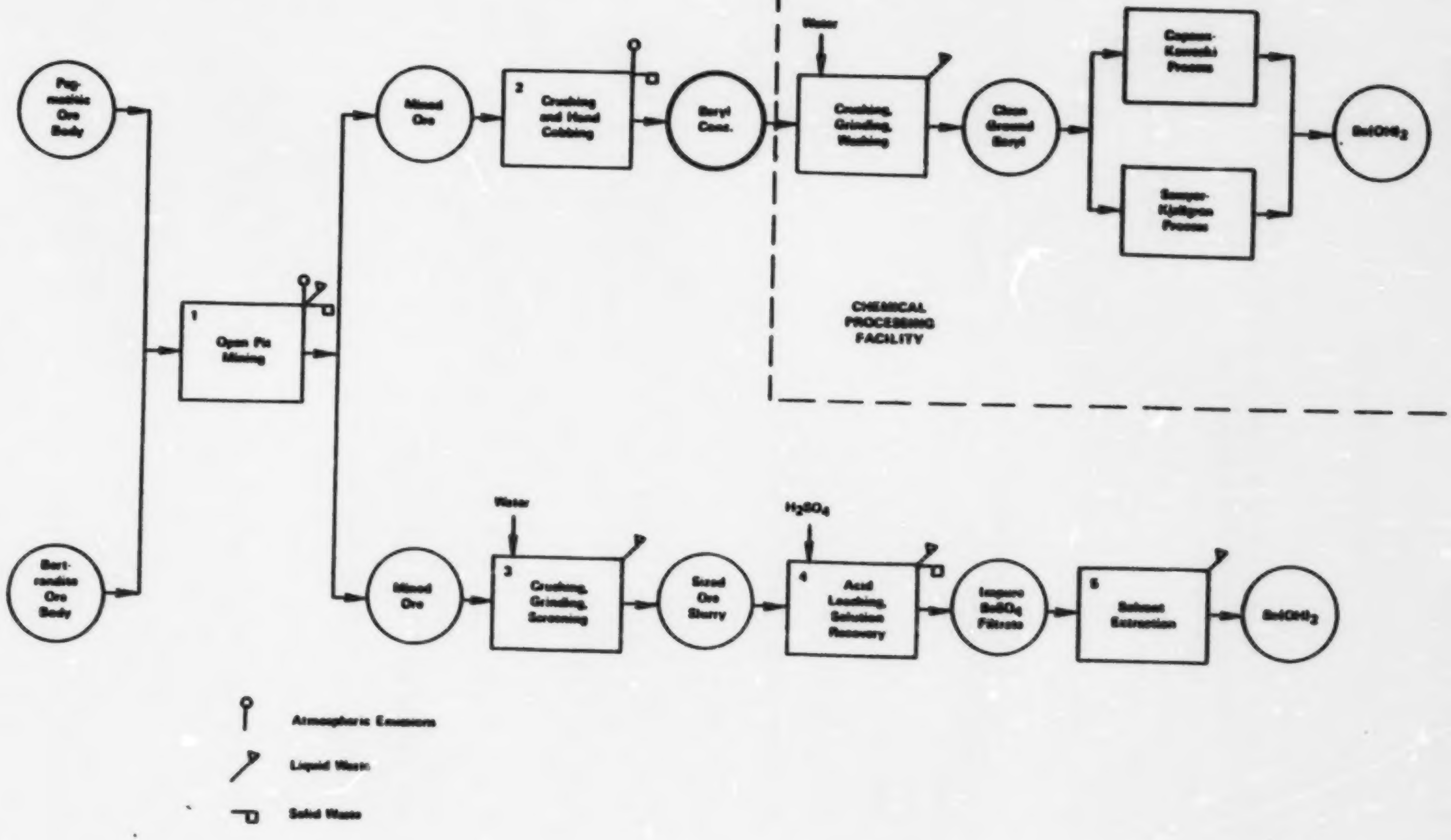
   (3) Private communications with members of the BCL staff who have consulted producers on energy requirements.

Beryllium

The world production of beryllium ore (of more than one type but equivalent to the mineral beryl containing 11 percent beryllium oxide, BeO) was about 5000 tons in each of the last several years. While more than this amount is being used by the United States on an annual basis, considerable amounts used are from stockpiles. The U.S. production of beryllium ore (from beryl containing ore bodies in Colorado and South Dakota and from the Utah bertrandite deposit) represents less than half of the total world production. The exact U.S. production figures for beryllium ores are withheld to avoid disclosing company confidential data.

Beryl is frequently found in rather large crystals in pegmatite deposits which permits the recovery of beryl in an unadulterated crystal form. Hand sorted (also know as hand cobbed) concentrates of beryl crystals are the common product from pegmatite mining operations. The bertrandite deposit in Utah contains considerable gangue material in an intimate mixture with the beryllium mineral. An acid-leaching process is therefore used to extract the value portion of the ore and this process results in a leach slurry. The beryllium content comes out of the ore in the acid-water-soluble compound, beryllium sulfate, $BeSO_4$, and is recovered as the filtrate from the leach slurry. Thus, the direct products of the industry are (a) beryl concentrate (in the form of crystals), and (b) beryllium sulfate in acidic solution.

Beryllium


Peg-
matitic
Ore
Body
Bert-
randite
Ore
Body
1
Open Pit
Mining
Mixed
Ore
2
Crushing
and Hand
Cobbing
Beryl
Conc.
Water
Crushing,
Grinding,
Washing
Clean
Ground
Beryl
Copaux-
Kawecki
Process
Sawyer-
Kjellgren
Process
Be(OH)₂
CHEMICAL
PROCESSING
FACILITY
Mixed
Ore
Water
3
Crushing,
Grinding,
Screening
Sized
Ore
Slurry
H₂SO₄
4
Acid
Leaching,
Solution
Recovery
Impure
BeSO₄
Filtrate
5
Solvent
Extraction
Be(OH)₂
Atmospheric Emissions
Liquid Waste
Solid Waste

Open-Pit Mining

1. Function - Simple open-pit mining methods are used to excavate beryl-containing granite pegmatites. In the U.S., these pegmatite deposits are usually mined primarily for feldspar, mica, quartz crystals, lithium-bearing minerals, and gem stones. Beryl, a crystalline beryllium-aluminum-silicate ($3BeO \cdot Al_2O_3 \cdot 6SiO_2$), is present in very low concentrations in these pegmatite deposits; 100 tons of rock yields about 1 ton of beryl.

2. Input Materials - Ammonium nitrate-fuel oil slurry explosives; 1 kg/metric ton of ore. Forty and 60 percent dynamite is also used.

3. Operating Parameters -

   Temperature: Ambient

   Pressure: Atmospheric

4. Utilities -

   Explosives, energy equivalent 2.91×10^8 joules/metric ton (80.9 kWhe/metric ton or 0.77×10^6 Btu/short ton) of rock. Diesel fuel, hauling, etc: 11.9 liters/metric ton (2.84 gal/short ton) of rock.

5. Waste Streams -

   Localized particulate and vapor emissions from drilling, blasting, and rock handling operations.

   Water run-off from mining operations

   Waste rock stockpiles

6. EPA Source Classification Code - None

7. References

(1) Chin, E., Preprint of Chapter on Beryllium for the 1973 Minerals Yearbook, Bureau of Mines, U. S. Department of the Interior, Washington, D.C., 5 p.

(2) Heindl, R. A., Chapter on Beryllium, Mineral Facts and Problems, 1970, Bureau of Mines Bulletin 650, Bureau of Mines, U. S. Department of the Interior, Washington, D.C., pp 489-501.

(3) Private communication with members of the BCL staff who have consulted producers for estimates on utilities energy requirements.

BERYLLIUM - PEGMATITE ORES PROCESS NO. 2

Crushing and Hand-Cobbing

1. **Function** - Beryl-containing ore from pegmatites is crushed and hand-sorted, sometimes on belts to reclaim beryl and other mineral values.

2. **Input Materials** - Broken pegmatite rock

3. **Operating Parameters** -

   Temperature: Ambient

   Pressure: Atmospheric

4. **Utilities** -

   Electric energy: 0.83×10^8 joules/metric ton (23 kWhe/metric ton or 0.22 Btu/short ton of pegmatite rock.

5. **Waste Streams** -

   Particulate emissions from crushing and handling

   Waste rock remaining after hand-cobbing is hauled to dumps

6. **EPA Source Classification Code** - None

7. **References** -

   (1) Chin, E., Preprint of Chapter of Beryllium for the 1973 Minerals Yearbook, Bureau of Mines, U.S. Department of the Interior, Washington, D.C., 5 p.

   (2) Heindl, R. A. Chapter on Beryllium, Mineral Facts and Problems, 1970, Bureau of Mines Bulletin 650, Bureau of Mines, U.S. Department of the Interior, Washington, D.C., pp 489-501.

   (3) Private communication with members of the BCL staff who have consulted producers for estimates on utilities energy requirements.

Open-Pit Mining of Bertrandite Ore

1. Function - Extraction of beryl-containing bertrandite ($4BeO \cdot 2SiO_2 \cdot H_2O$) ore from the largest domestic source of beryllium, the Spor Mountain bertrandite mine near Delta, Utah. In this location, bertrandite occurs erratically in altered tuff which lies close to the surface and thus can be mined by open-cut methods.

2. Input Materials - Ammonium nitrate fuel oil slurry explosives

3. Operating Parameters -

   Temperature: Ambient

   Perssure: Atmospheric

4. Utilities -

   Diesel-Electric Generators; Mining Operations; 118×10^8 joules/metric ton (3270 kWhe/metric ton or 31.1×10^6 Btu/short ton) of BeO.

5. Waste Streams -

   No mining dust; the ore is set (16-22 percent moisture)

   Water emissions from mining

   Considerable amounts of gangue, most of which is separated in the leaching step

6. EPA Source Classification Code - None

7. References -

(1) Chin, E., Preprint of Chapter on Beryllium for the 1973 Minerals Yearbook, Bureau of Mines, U.S. Department of the Interior, Washington, D.C., 5 p.

(2) Heindl, R. A., Chapter on Beryllium, Mineral Facts and Problems, 1970, Bureau of Mines Bulletin 650, Bureau of Mines, U.S. Department of the Interior, Washington, D.C., pp 489-501.

(3) Private communication with members of the BCL staff who have consulted producers for estimates on utilities energy requirements.

Crushing, Grinding, and Screening

1. Function - Bertrandite ($4BeO \cdot 2SiO_2 \cdot H_2O$) ores at the Spor Mountain mine in Utah contain only an average of 0.65 percent beryllium (ranges from 0.5-1.5 percent). To free the bertrandite minerals from associated gangue, the ore is wet crushed, wet ground, and wet screened to a thixotropic slurry in preparation for a leaching step.

2. Input Materials - Open-pit mined ore from the Spor Mountain deposit and water.

3. Operating Parameters -

   Temperature: Ambient

   Pressure: Atmospheric

4. Utilities - (Includes pumping energy for leach solutions)

   Diesel-Electric Power; 13.6 X 10^8 joules/metric ton (378 kWhe/metric ton or 3.6 x 10^6 Btu/short ton) of ore.

5. Waste Streams -

   No gaseous emissions: Wet crushing, grinding, and screening

   No water emissions per se, since ore slurry goes on to the leaching operation. Spills may occur.

   The generation of waste rock occurs in the next step, leaching.

6. EPA Source Classification Code - None

7. References -

(1) Chin, E., Preprint of Chapter on Beryllium for the 1973 Minerals Yearbook, Bureau of Mines, U. S. Department of the Interior, Washington, D.C., 5 p.

(2) Heindl, R. A., Chapter on Beryllium, Mineral Facts and Problems, 1970, Bureau of Mines Bulletin 650, Bureau of Mines, U. S. Department of the Interior, Washington, D.C., pp 489-501.

(3) Private communication with members of the BCL staff who have consulted producers for estimates on utilities energy requirements.

Acid Solution Leaching

1. Function - the bertrandite ($4BeO \cdot 2SiO_2 \cdot H_2O$) ore slurry from the wet grinding and screening operation is leached in 10 percent sulfuric acid solution to put the beryllium in solution thus separating it from the insoluble gangue. After leaching, solids are separated and washed by countercurrent displacement in a series of thickeners.

2. Input Materials - A slurry of wet ground bertrandite ore, concentrated sulfuric acid, water.

3. Operating Parameters

   Temperature: Ambient

   Pressure: Atmospheric

4. Utilities - (Includes energy required for crushing and grinding besides that of leach pumping).

   Diesel-Electric Power; 13.6×10^8 joules/metric ton (378 kWhe/metric ton or 3.6×10^6 Btu/short ton) of ore.

5. Waste Streams -

   Acid residue of slurries from leaching obtained from the thickeners are combined with a sufficient amount of alkaline solution to achieve a pH of 8 to 10 in the slurry of solids discharged to waste storage lagoons.

6. EPA Source Classification Code - None

7. References -

(1) Chin, E., Preprint of Chapter on Beryllium for the 1973 Minerals Yearbook, Bureau of Mines, U. S. Department of the Interior, Washington, D.C., 5 p.

(2) Heindl, R. A., Chapter on Beryllium, Mineral Facts and Problems, 1970, Bureau of Mines Bulletin 650, Bureau of Mines, U. S. Department of the Interior, Washington, D.C., pp 489-501.

(3) Private communication with members of the BCL staff who have consulted producers for estimates on utilities energy requirements.

Solvent Extraction

1. Function - Beryllium, having been put into solution in dilute 10 percent sulfuric acid as an impure beryllium sulfate, is selectively extracted using an organic chelating agent, di-2-ethylhexyl phosphoric acid in a kerosene diluent. The extracted beryllium in the organic solvent is separated from the spent leach liquor (raffinate) in settling tanks, after which, in subsequent steps, the organic solution containing the chelated beryllium ions free of impurities is remixed with an alkaline stripping solution to produce a solution containing an alkaline berylate compound. The stripped organic phase is recycled. Beryllium hydroxide is precipitated from the alkaline berylate solution by boiling, and is separated from the filtrate by centrifuging and filtering; the alkaline filtrate is recycled.

2. Input Materials - Impure beryllium sulfate in acid solution; kerosene containing an organic chelating agent; alkaline stripping solution

3. Operating Parameters -

   Temperature: Extraction and stripping - Ambient
   Precipitation of BeOH from stripping solution; boiling

   Pressure: Atmospheric

4. Utilities -

   Pumping, diesel-electric power: 16.7 x 10^8 joules/metric ton (464 kWhe/metric ton or 4.42 x 10^6 Btu/short ton) of bertrandite ore.

5. Waste Streams -

   Vapor escape from boiling alkaline berylate solution

   No toxicological hazards

   Spent leach liquor (raffinate)

   Spills of organic solution in the extraction circuit

   Spills of alkaline stripping solutions

6. EPA Source Classification Code - None exists

7. References -

(1) Chin, E., Preprint of Chapter of Beryllium for the 1973 Minerals Yearbook, Bureau of Mines, U.S. Department of the Interior, Washington, D.C., 5 p.

(2) Heindl, R. A., Chapter on Beryllium, Mineral Facts and Problems, 1970, Bureau of Mines Bulletin 650, Bureau of Mines, U.S. Department of the Interior, Washington, D.C., pp 489-501.

(3) Private communication with members of the BCL staff who have consulted producers for estimates on utilities energy requirements.

Copper

Next to aluminum, copper is the leading nonferrous metal consumed in the United States. We are practically self-sufficient in providing our copper requirements from our mines and treatment facilities (95 per cent). A vast network of mines and treatment facilities distributed over several states produces about 2.3 million tons of copper annually. About 90 percent of our total primary copper production is provided by 25 leading U.S. mines.

The most important copper-ore type in the United States is the so-called "porphyry" copper deposits. These are extensive masses of rock throughout which crystals of various copper minerals are more or less uniformly disseminated, and which, although low grade, may profitably be mined on a massive nonselective scale. The porphyry copper deposits account for the major portion of copper production. Porphyry ores are usually mined by open-pit methods.

Economically important concentrations of copper minerals are frequently found in association with minerals of other metals. The most frequent associations are copper with lead or zinc, copper with gold and silver, copper with molybdenum, and copper with any combination of these metals. In addition, iron in the form of pyrite is also a common associate. Other metallics such as nickel, bismuth, antimony, etc. in usually small quantities, also are found with copper minerals.

Due to the great variety of mineral assemblages found in copper deposits, including minerals of other metals and nonmetals, it is convenient to classify copper ores according to their predominant mineral characteristics and economic grade.

(a) High-grade sulfide ores. These are generally obtained from underground operations and may range from about 3 to 10 percent copper.

(b) Concentrating-grade ores. As mined, these ores will contain from about 0.6 to about 1 or more percent copper mostly as sulfide. They account for about 75 to 80 percent of primary copper production in the country.

(c) Native copper ores. The only important deposits containing native copper ores occur in Michigan.

(d) Low-grade (or leaching grade) ores. These are the ores containing significant quantities of copper as sulfide and/or oxide and which cannot be economically concentrated by the basic process. They may contain only a few tenths percent copper. In mining, such ores are segregated and leached.

(e) Very low grade ores. In some cases the quantity of copper in the country rock is so low that it is not economical to remove the rock for copper extraction. Such deposits may be "mined" by a leaching-in-place process.

(f) Mixed sulfide-oxide ores. These are ores in which the sulfides and oxide minerals are present in approximately equal amounts, and which require special treatment to yield an economic level of recovery. Such ores may range in grade from about 0.6 to 2 percent copper, with the bulk of them below 1 percent.

The several processes used to recover the copper from the different types of ore result in several different concentrated products which are subsequently sent off for further processing (i.e., smelting and refining). The products of mining and beneficiating processes can be classified as:

(a) High-grade ore concentrate. For the purposes of this report, only high grade ores going directly to smelting are considered high grade. Those going to a concentrator are considered as a concentrating grade.

(b) Filter cake. The concentrates produced by milling operations are always in the form of filter cake containing about 20 percent by weight of water and, on a dry basis, from about 20 to 35 percent copper.

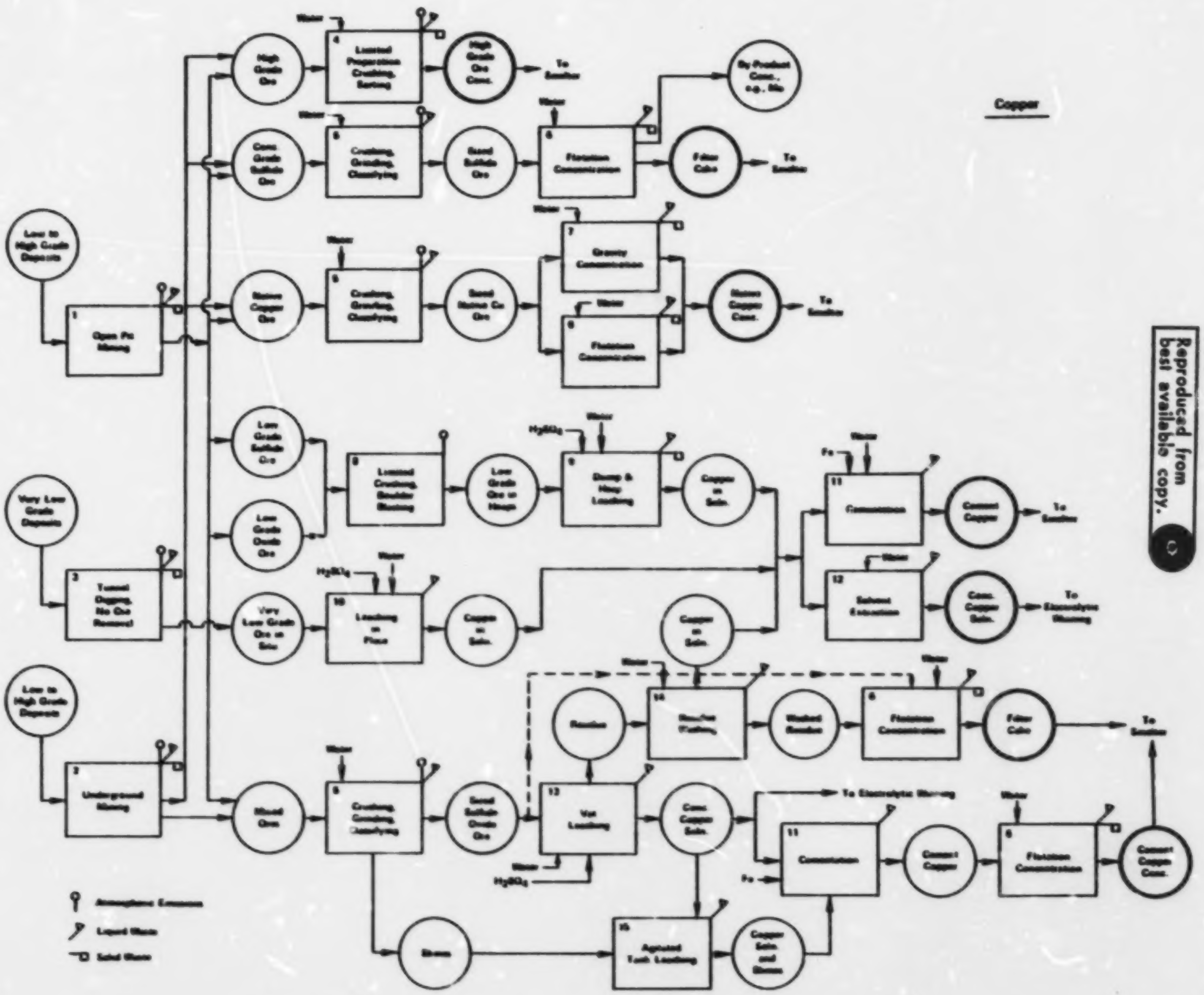
(c) Native copper concentrate. Native copper ores predominantly occur in Upper Peninsula Michigan. In the mines currently worked in this area, native copper constitutes only a small percentage of the value, with covellite and chalcocite being the major copper minerals. The ores are now treated by more or less conventional concentrating techniques to yield a conventional filter cake.

(d) Cement copper. The product of cementation is called cement copper. It is a relatively impure material containing from about 70 to 90 percent copper and contaminated with such materials as scrap iron, basic copper and iron sulfates, and oxides.

(e) Concentrated copper solution. The pregnant solutions derived from leaching normally contain up to several grams per liter of copper as copper sulfate. Solutions from this type of leaching are too dilute for electrolysis, and must be treated by an intermediate concentration process such as cementation or solvent extraction.

The flowsheet of the copper mining and beneficiating industry shows the various types of ores and the processing steps that are involved in producing concentrated products. The processing steps are numbered and the numbers are keyed with the subsequent text in which pertinent explanations and details are presented.

Copper


Low to High Grade Deposits
Very Low Grade Deposits
Low to High Grade Deposits
1 Open Pit Mining
2 Tunnel Digging, No Ore Removal
3 Underground Mining
High Grade Ore
Conc. Grade Sulfide Ore
Native Copper Ore
Low Grade Sulfide Ore
Low Grade Oxide Ore
Very Low Grade Ore in Situ
Mixed Ore
4 Limited Preparation Crushing, Sorting
5 Crushing, Grinding, Classifying
8 Limited Crushing, Boulder Blasting
9 Dump & Heap Leaching
10 Leaching in Place
High Grade Ore Conc.
To Smelter
By-Product Conc., e.g., Mo
Sized Sulfide Ore
6 Flotation Concentration
Filter Cake
Sized Native Cu Ore
7 Gravity Concentration
Native Copper Conc.
Low Grade Ore in Heaps
Copper in Soln.
11 Cementation
Cement Copper
12 Solvent Extraction
Conc. Copper Soln.
To Electrolytic Winning
Sized Sulfide Oxide Ore
13 Vat Leaching
Residue
14 Residue Washing
Washed Residue
Slimes
15 Agitated Tank Leaching
Copper Soln. and Slimes
Cement Copper Conc.
Water
Fe
H2SO4
Atmospheric Emissions
Liquid Waste
Solid Waste

Reproduced from best available copy.

COPPER - LOW- TO HIGH-GRADE DEPOSITS — PROCESS NO. 1

Open-Pit Mining of Copper Ores

1. Function - Open-pit mining involves the removal of ore from deposits at or near the surface by a cycle of operations consisting of drilling blast holes, blasting the ore, loading the broken ore onto trucks or rail cars, and transporting it to the concentrators. (In a few cases, blasting is not required; ore is "ripped" by bulldozers and loaded.) Barren surface rock overlaying the deposit must be removed to uncover the ore body; such overburden may be up to (and, in one case, even exceeding) 150 meters (500 feet) thick.

2. Input Materials - Explosives (ammonium nitrate-fuel oil) 0.54 Kg/metric ton (1.1 lb./short ton) of material mined. Water in arid areas.

3. Operating Parameters -

   Temperature: Ambient

   Pressure: Atmospheric

4. Utilities -

   Typical Case -

   Electric Energy: 0.22×10^8 joules/metric ton (6.1 kWhe/metric ton or 0.06×10^6 Btu/short ton) of ore (0.7 percent copper, average)

   Natural Gas: 0.047 cu meters/metric ton (1.5 cu ft/short ton) of ore

   Diesel Fuel: 1.13 liters/metric ton (0.27 gal/short ton) of ore

5. Waste Streams -

   Airborne particulates from blasting

   Water run-off (including water used for dust control in various mining operations)

   Storage of solid overburden wastes

6. EPA Source Classification Code - None

7. References

(1) Private communication with BCL staff who have visited open-pit copper mines and consulted with the staff of various copper companies; utility energy usage estimates were based on experience in eight representative open-pit mines.

(2) Explosives consumption based on experience at two mines.

(3) "Development Document for Proposed Effluent Limitations Guidelines and New Performance Standards for the Primary Copper Subcategory of the Copper, Lead, and Zinc Segment of the Nonferrous Metals Point Source Category", prepared by Battelle's Columbus Laboratories for the Environmental Protection Agency, Contract No. 68-01-1518, December 1973.

COPPER - LOW- TO HIGH-GRADE ORE PROCESS NO. 2

Underground Mining

1. Function - Underground mining involves the removal of ores from deep deposits by a number of techniques, the selection of which depends on the characteristics of the ore body. There are two main methods, caving and supported stoping. Caving methods used in the mining of copper include block caving used in large, homogeneous, structurally weak ore bodies, and top-slicing for smaller and more irregular ore bodies. Supported stoping methods are used to mine veins and flat deposits of copper ore. There are two types, naturally supported and artificially supported. Natural support stoping methods include open stoping for small ore bodies and open stoping with natural pillar support for wider ore bodies, both of which have structurally strong foot walls (floors in bedded deposits) and hanging walls (roofs in bedded deposits). Artificially supported stoping methods include shrinkage stoping for steeply dipping tabular-shaped deposits having fairly strong foot and hanging walls, and little waste; cut and fill stoping for similarly shaped deposits having weak walls; and timbered or square-set stoping methods for cases where the ore is weak and the surrounding rock is so weak that temporary timbered support is necessary as an interim measure prior to filling with broken waste rock.

2. Input Materials - Nitroglycerine explosives (dynamite). About 0.5 Kg/metric ton (1 lb/short ton) of ore mined.

3. Operating Parameters -

   Temperature: Ambient

   Pressure: Atmospheric

4. Utilities -

   Electric Energy: Amount used varies widely depending upon method of mining and type of ore body. Mean value estimated to be about 0.32×10^8 joules/metric ton (9kWhe/metric ton or 0.086×10^6 Btu/short ton)

5. Waste Streams -

Mine water effluent from seepage and water used in mining such as in drilling

Storage of solid gangue

6. EPA Source Classification Code - None

References -

(1) U.S. Census of Mineral Industries, Major Group 10 (Copper, lead, zinc, gold, and silver ores) Table 3A, p 10B-11; Table 7, pp 10-22.

(2) Wideman, F. L., Chapter on Copper, Mineral Facts and Problems, 1965 edition, Bureau of Mines, U.S. Department of the Interior, pp 263-276.

Driving Drainage Tunnels Under Porous Ore-Bodies for In-Place Leaching

1. Function - Drainage tunnels accumulate the dilute sulfuric acid solutions of copper leached from overlying shattered, broken, or otherwise porous ore bodies which are too low grade to be processed profitably by other methods.

2. Input Materials - Nitroglycerine explosives. About 0.5 Kg/metric ton (1 lb/short ton) of ore mined.

3. Operating Parameters -

   Temperature: Ambient

   Pressure: Atmospheric

4. Utilities -

   Electric Energy: (Air compressors for drilling, etc.) Very low on the basis of per ton of cement copper removed by leaching methods in subsequent processing. (In-place leaching cycles are measured in years.)

5. Waste Streams -

   Mine drainage effluent

   Waste rock storage

6. EPA Source Classification Code - None

7. References -

(1) U. S. Census of Mineral Industries, Major Group 10 (Copper, lead, zinc, gold, and silver ores) Table 3A, p 10B-11; Table 7, pp 10-22.

(2) Wideman, F. L., Chapter on Copper, Mineral Facts and Problems, 1965 edition, Bureau of Mines, U. S. Department of the Interior, pp 263-276.

COPPER - HIGH-GRADE ORE

PROCESS NO. 4

Crushing and Sorting

1. Function - Copper ores containing upwards of about 15 percent copper are smelted directly; however, it is not possible to mine only the ore deposit, some associated gangue is present which is removed by crushing and gravity separation, usually jigging.

2. Input Materials - High-grade copper ore with associated gangue and water.

3. Operating Parameters - (Crushing and Jigging)

   Temperature: Ambient

   Pressure: Atmospheric

4. Utilities -

   Electric Energy: 0.11×10^8 joules/metric ton (3kWhe/metric ton or 0.029×10^6 Btu/short ton) of ore.

5. Waste Streams -

   Dust particulates in crushing

   Water run off from jigs

   Storage of waste rock

6. EPA Source Classification Code - None

7. References -

   (1) Private communication with BCL staff who have visited mines and consulted with producers.

   (2) Wideman, F. L., Chapter on Copper, Mineral Facts and Problems, 1965 edition, Bureau of Mines, U. S. Department of the Interior, pp 263-276.

COPPER - CONCENTRATION GRADE OF SULFIDE ORE PROCESS NO. 5

Crushing, Grinding, and Classifying

1. Function - Ore containing more than about 0.4 percent copper is concentrated for further treatment at the smelter. To accomplish this, it is crushed, then ground to a fineness sufficient to separate the copper mineral particles from associated gangue, the classifier is used to separate and return ground oversize to the grinding mills.

2. Input Materials - Copper ore and water to grinding mills and classifiers.

3. Operating Parameters - Crushing is a separate operation, usually done dry. Grinding is usually done wet in a closed circuit with a classifier.

   Temperature: Ambient

   Pressure: Atmospheric

4. Utilities -

   Crushing: 0.11×10^8 joules/metric ton (3.0 kWhe/metric ton or 0.029×10^6 Btu/short ton) of ore.

   Grinding and Classifying: 0.56×10^8 joules/metric ton or 0.15×10^6 Btu/short ton) of ore.

5. Waste Streams -

   Dust, particulates from the crushing operation

   Water, effluents from grinding

   Waste rock (associated with crushing operation at mine shaft)

6. EPA Source Classification Code - None

   References -

   (1) Private communication with BCL staff who have visited mines and consulted with producers.

   (2) Wideman, F. L., Chapter on Copper, Mineral Facts and Problems, 1965 edition, Bureau of Mines, U. S. Department of the Interior, pp 263-276.

Flotation of Concentration Grades of Sulfide Ores

1. Function - Copper sulfide minerals, having been freed from attached gangue minerals such as silicates by grinding, are separated from them by a "flotation" technique which depends on differences in the surface characteristics between the sulfide mineral particles and the particles of gangue. The ground ore is agitated by rising air bubbles in cells containing water, various oils, and chemical reagents which cause the sulfide mineral particles to be selectively wetted by the oil present and become attached to the rising air bubbles, whereupon they rise to the surface of the cell and are scraped off.

2. Input Materials - Ground ore, water, oils, inorganic, and organic flotation reagents such as lime and sodium carbonate for pH regulation, pine oil and cresylic acid as frothing agents, xanthates and fatty acids as collectors, sodium cyanide and tannic acid as depressants, sodium silicates as dispersants, polysulfides as activators, and sodium monosulfides as precipitating agents.

3. Operating Parameters - Flotation cells are operated at ambient temperature and pressure.

4. Utilities -

   Electric Energy: 0.23×10^8 joules/metric ton (6.5 kWhe/metric ton or 0.062×10^6 Btu/short ton) ground ore input.

5. Waste Streams -

   Slurries containing tailings, reagent losses to tailings

   Solid tailings remaining after dewatering

6. EPA Source Classification Code - None

7. References -

(1) Private communication with BCL staff who have visited mines and consulted with producers.

(2) Wideman, F.L., Chapter on Copper, Mineral Facts and Problems, 1965 edition, Bureau of Mines, U. S. Department of the Interior, pp 263-276.

COPPER - NATIVE COPPER ORES PROCESS NO. 5

Crushing, Grinding, and Classifying of Native Copper Ores

1. Function - Native copper ores occur in large deposits only in the Keweenaw Peninsula of Michigan. At present, only two shafts are in operation with a 680-metric ton (750 short ton) - per-day pilot mill under construction. Practice has been to crush the ore at the mine shaft house, and reduce it further at the mill in stamp or hammer mills. After an interim jigging operation to remove large pieces of native copper (which go directly to the smelter), the ore is wet ground in closed circuit with classifiers in pebble mills in preparation for further separation processes.

2. Input Materials - Underground mined ore and water

3. Operating Parameters -

   Crushing (Dry)

   Wet grinding and classification

   Temperature: Ambient

   Pressure: Atmospheric

4. Utilities -

   Crushing: 0.1×10^8 joules/metric ton (3.0 kWhe/metric ton or 0.029×10^6 Btu/short ton) of ore.

   Grinding and Classifying: 0.56×10^8 joules/metric ton or 0.15×10^6 Btu/short ton) of ore.

5. Waste Streams -

   Dust, particulates from the crushing operation

   Water, effluents from grinding

   Waste rock (associated with crushing operation at mine shaft)

6. EPA Source Classification Code - None

7. References -

(1) Splide, D. E., The Keweenaw Venture: Homestake's Search for Native Copper; paper given at the 104th AIME Annual Meeting, New York Hilton Hotel, New York, N. Y., February 17, 1975.

(2) Private communication with BCL staff who have visited mines and consulted with producers.

(3) Wideman, F. L., Chapter on Copper, Mineral Facts and Problems, 1965 edition, Bureau of Mines, U. S. Department of the Interior, pp 263-276.

Flotation of Ground Native Copper Ores

1. Function - The tailing from the coarse gravity concentrators are reground fine enough to free minute particles of native copper from adhering gangue. The finely ground ore is agitated by rising air bubbles in cells containing water, various oils, and organic and inorganic reagents which cause the surface of the copper particles to be hydrophobic and aerophilic, and are thus selectively wetted by the oil and become attached to the rising air bubbles, after which they rise to the surface where they are scraped off.

2. Input Materials - Ground ore, water, oils, inorganic, and organic flotation reagents.

3. Operating Parameters - Flotation cells are operated at ambient temperature and pressure.

4. Utilities -

   Electric Energy: 0.23×10^8 joules/metric ton (6.5 kWhe/metric ton or 0.062×10^6 Btu/short ton) ground ore input

5. Waste Streams -

   Slurries containing tailings, reagent losses to tailings

   Solid tailings remaining after dewatering

6. EPA Source Classification Code - None

7. References -

(1) Private communication with BCL staff who have visited mines and consulted with producers.

(2) Wideman, F. L., Chapter on Copper, Mineral Facts and Problems, 1965 edition, Bureau of Mines, U. S. Department of the Interior, pp 263-276.

COPPER - NATIVE COPPER ORES PROCESS NO. 7

Gravity Concentration

1. Function - Native copper deposits of the Keweenaw Peninsula of Michigan occur in amygdaloid and conglomerate beds of the Keweenawan Portage Lake Lava series. It is disseminated throughout the conglomerate in varying degrees of fineness; the amygdaloidal copper deposits tend to be formed in almond-shaped vesticles of relatively large size. Native copper, as it occurs in the deposits, is quite pure and malleable, and thus the large lumps and coarse particles of native copper occurring in these deposits do not lend themselves to fine grinding. Accordingly, the copper in the deposits is separated from the waste rock in stages, the large lumps and coarse particles are separated first by gravity concentration. Large pieces, liberated in the stamp and hammer mills, are separated first in jigs. The overflow from the jigs is coarse ground and separated by tabling. Remaining fine particles of copper in the table tailings discharge are released by further grinding and separated in flotation cells.

2. Input Materials - Native copper ore and water.

3. Operating Parameters - Jigs and tables are operated at ambient temperature and pressure.

4. Utilities -

   Electric Energy: 0.14×10^8 joules/metric ton (9kWhe/metric ton or 0.038×10^6 Btu/short ton) of ore.

5. Waste Streams -

   Water overflow in jigs and tables

6. EPA Source Classification Code - None

7. References -

   (1) Splide, D. E., The Keweenaw Venture: Homestake's Search for Native Copper; paper given at the 104th AIME Annual Meeting, New York Hilton Hotel, New York, N. Y., February 17, 1975.

(2) Private communication with BCL staff who have visited mines and consulted with producers.

(3) Wideman, F. L., Chapter on Copper, Mineral Facts and Problems, 1965 edition, Bureau of Mines, U. S. Department of the Interior, pp 263-276.

Crushing of Low-Grade Ore for Leaching

1. Function - In handling copper ores from open pit mines, those having more than 0.4 percent copper are concentrated, those having less than this amount are deposited in waste rock dumps and leached. In heap leaching (mainly used on oxide ores), some of the ore may require crushing, and in some cases, large rock pieces require blasting, to insure contact of the leach solution with finely disseminated copper minerals.

2. Input Materials - Low-grade oxide or sulfide copper ore.

3. Operating Parameters -

   Temperature: Ambient

   Pressure: Atomospheric

4. Utilities -

   Electric Energy: Very low. In the four open pit mines that produce most of the cement copper in the U.S., waste ore for leaching is not crushed; neither is it crushed in a typical heap leaching operations on soft oxide ore produced from an open-pit mine at the rate of 7,260 metric tons (8,000 short tons) of ore per day.

5. Waste Streams -

   Dust, particulates from dumping ore in heaps or dumps; also from a limited amount of crushing.

6. EPA Source Classification Code - None

7. References -

   (1) Power, Kenneth L., Operation of the First Commercial Copper Liquid Ion Exchange and Electrowinning Plant, Proc., Extractive Metallurgy Division Symposium on Copper Metallurgy, Denver, February 15-19, 1970; The Metallurgical Society of the AIME, New York, N. Y., 1970, pp 1-26.

   (2) Private communication with BCL staff who have visited mines and consulted with producers.

(3) Wideman, F. L., Chapter on Copper, Mineral Facts and Problems, 1965 edition, Bureau of Mines, U.S. Department of the Interior, pp 263-276.

COPPER - LOW-GRADE SULFIDE AND OXIDE ORES PROCESS NO. 9

Dump and Heap Leaching

1. Function - Subore grades of copper from open pit mines having less than 0.4 percent copper are deposited in waste rock heaps (dumps) and leached. The leaching cycle in dump leaching is measured in years. Heap leaching is used to recover copper from weathered ore, and in some cases from material from mine dumps. The material is placed in alternately fine and coarse layers in prepared water-tight basins up to a thickness of about 6.1 meters (20 feet). In a typical heap-leaching operation, the spent leaching solution containing sulfuric acid, with water additions, is recycled; additions of sulfuric acid to this solution are made during the initial stages of a 6-month leach cycle.

2. Input Materials - Broken ore, spent leach, water, and dilute sulfuric acid sometimes ferric sulfate and bacteria. Various bacteria such as thiobacillus ferrooxidans are used to oxidize ferric iron and reduce sulfur compounds. Amounts of sulfuric acid used will vary. A typical amount would be 12.5 Kg/metric ton (25 lb/short ton) of mill feed.

3. Operating Parameters - Leach dumps and heaps are open to the weather; ambient temperature and

4. Utilities -

   Electric Energy: 0.2×10^8 joules/metric ton (5.5 KWhe/metric ton or 0.052×10^6 Btu/short ton) of ore.

5. Waste Streams -

   Storage of spent leaching solutions (recycled), spills

   Storage of solid leached material in dumps and heaps

6. EPA Source Classification Code - None

7. References -

   (1) Power, Kenneth L., Operation of the First Commercial Copper Liquid Ion Exchange and Electrowinning Plant, Proc., Extractive Metallurgy Division Symposium on Copper Metallurgy, Denver, February 15-19, 1970; The Metallurgical Society of the AIME, New York, N.Y., 1970, pp 1-26.

(2) Private communication with BCL staff who have visited mines and consulted with producers.

(3) Wideman, F. L., Chapter on Copper, Mineral Facts and Problems, 1965 edition, Bureau of Mines, U. S. Department of the Interior, pp 263-276.

Leaching in Place

1. Function - Lean ore bodies containing less than 0.4 percent copper (as sulfide or oxides) which are broken or shattered to allow contact with air and water are leached in place; the sulfide minerals are exposed and oxidized by alternate and intermittent contact with air and water to form (along with any oxides present) a copper sulfate leach solution which is accumulated in drainage tunnels driven under the ore.

2. Input Materials - Explosives for tunnel construction and to achieve permeation of the ore body by leach solutions, water, spent leach solution, dilute sulfuric acid, sometimes ferric sulfate and bacteria (to oxidize metallic sulfides to water soluble sulfates).

3. Operation Parameters - Ore bodies leached by in-place methods are open to the weather; temperature and pressure are ambient, the leach cycle is measured in years.

4. Utilities -

   Electric Energy: (Pumping) 0.2×10^8 joules/metric ton (5.5 kWhe/metric ton or 0.052×10^6 Btu/short ton) of ore.

5. Waste Streams -

   Stripped solutions are ponded for recycling. Spills.

   Areas of in-place leached shattered ore which may require reclamation.

6. EPA Source Classification Code - None

7. References -

   (1) Power, Kenneth L., Operation of the First Commercial Copper Liquid Ion Exchange and Electrowinning Plant, Proc., Extractive Metallurgy Division Symposium on Copper Metallurgy, Denver, February 15-19, 1970; The Metallurgical Society of the AIME, New York, N. Y., 1970, pp 1-26.

(2) Private communication with BCL staff who have visited mines and consulted with producers.

(3) Wideman, F. L., Chapter on Copper, Mineral Facts and Problems, 1965 edition, Bureau of Mines, U. S. Department of the Interior, pp 263-276.

COPPER - LOW GRADES OF SULFIDE ORE
LOW GRADES OF OXIDE ORE
VERY LOW GRADES OF ORE IN SITU

PROCESS NO. 11

Cementation of Copper From Leach Solutions Obtained in Dump and Heap Leaching

1. Function - Copper in solution in the dilute acid leach liquor is precipitated by replacement with iron. In typical practice, the leach liquor, containing 0.5-1.5 g/l of copper, flows through launders containing scrap iron (usually detinned steel scrap or burned tin cans) and plates out a loosely adherent "cement" copper on the iron surfaces which, in a later cycle, is washed off these surfaces into a settling basin. Automatically controlled cone precipitators which "self clean" the copper precipitates have been introduced in the industry during the late 1960's.

2. Input Materials - Leach solution, scrap iron, detinned steel scrap, or burned tin cans. Water jets or sprays for removing cement copper from the iron surfaces.

3. Operating Parameters -

   Temperature: Ambient

   Pressure: Atmospheric

4. Utilities -
   Electric Energy: (Pumping--includes leaching) 0.2×10^8 joules/metric ton (5.5 kWhe/metric ton or 0.052×10^6 Btu/short ton) of ore. 0.16×10^8 joules/kilograms (4.3 kWhe/kilogram or 0.020×10^6 Btu/pound of cement copper (-0.3 percent copper, 30 percent recovery.)

5. Waste Streams -

   Stripped solutions are ponded for recycling. Spills.

6. EPA Source Classification Code - None

7. References -

   (1) Pings, W. B., and Rau, Earl L., Recent Trends in Copper Metallurgy, Mineral Industries Bulletin, Colorado School of Mines Research Foundation, Inc., Vol II, No. 4, July, 1968, pp 1-12.

COPPER - LOW GRADES OF SULFIDE AND OXIDE ORE PROCESS NO. 12

Solvent Extraction (Liquid Ion Exchange)

1. Function - Leach liquors containing copper in weak acid solution may be selectively removed from the solution by contact with a liquid ion-exchange reagent. In the two commercial installations in the United States, copper in the leach liquors is extracted with a 6-7-percent-by-volume solution of LIX-64 (a proprietary organic ion-exchange compound produced by General Mills) in a kerosene solvent. In the extraction reaction, the hydrogen ions of the reagent are replaced with copper ions. In a following stripping cycle, the copper in the organic medium is stripped with acid electrolyte from the electrolytic recovery section of the plant. In this stripping cycle, the copper ions are reexchanged with hydrogen ions, thus regenerating the ion exchange reagent for recycling to the extraction system, and concentrating the electrolyte. Because the ion-exchange reagent is highly selective, the enriched electrolyte is essentially impurity free.

2. Input Materials - Leach solution, liquid ion-exchange reagent in an inert organic solvent such as kerosene (both recycled). Make-up water. Dilute sulfuric acid additions.

3. Operating Parameters - Depending on the climate, the extraction circuit may require some heat input (via heat exchangers) during the winter months to insure proper separation of the organic solution of ion exchange reagent and the aqueous electrolyte.
   Temperature: 27 C (80 F)

   Pressure: Atmospheric

4. Utilities -

   Electric Energy: About 0.04×10^8 joules/metric ton (1.1 kWhe/metric ton or 0.010×10^6 Btu/short ton) of copper produced, required for pumping of solutions, and operation of flotation cells (without additional reagents) to remove entrained organic ion-exchange reagent from the pregnant electrolytic which, if present, causes copper to precipitate as sponge or cement copper rather than as a dense deposit.

5. Waste Streams -

Possible seepage losses under dumps and heaps

Seepage losses or spills from pregnant liquor pond

Spillage of dilute sulfuric acid

Filtered slimes from pregnant solution

Waste rock in heaps and dumps

6. EPA Source Classification Code - None

7. References -

(1) Power, Kenneth L., Operation of the First Commercial Copper Liquid Ion Exchange and Electrowinning Plant, Proc., Extractive Metallurgi Division Symposium on Copper Metallurgy, Denver, February 15-19, 1970; The Metallurgical Society of the AIME, New York, N. Y., 1970, pp 1-26.

(2) Private communication with BCL staff who have visited mines and consulted with producers.

(3) Wideman, F. L., Chapter on Copper, Mineral Facts and Problems, 1965 edition, Bureau of Mines, U. S. Department of the Interior, pp 263-276.

COPPER - MIXED SULFIDE AND NONSULFIDE ORES PROCESS NO. 5

Crushing, Grinding, and Classifying

1. Function - Ore containing more than about 0.4 percent copper is concentrated for further treatment at the smelter. To accomplish this, it is crushed, then ground to a fineness sufficient to separate the copper mineral particles from associated gangue, the classifier is used to separate and return ground oversize to the grinding mills.

2. Input Materials - Copper ore and water to grinding mills and classifiers.

3. Operating Parameters - Crushing is a separate operation, usually done dry. Grinding is usually done wet in a closed circuit with a classifier.

   Temperature: Ambient

   Pressure: Atmospheric

4. Utilities -
   Crushing: 0.11 x 10^8 joules/metric ton 93.0 kWhe/metric ton or 0.029 x 10^6 Btu/short ton) of ore.

   Grinding and Classifying: 0.56 x 10^8 joules/metric ton (15.5 kWhe/metric ton or 0.15 x 10^6 Btu/short ton) of ore.

5. Waste Streams -

   Dust, particulates from the crushing operation

   Water, effluents from grinding

   Waste rock (associated with crushing operation at mine shaft)

6. EPA Source Classification Code - None

7. References -

   (1) Private communication with BCL staff who have visited mines and consulted with producers.

   (2) Wideman, F. L., Chapter on Copper, Mineral Facts and Problems, 1965 edition, Bureau of Mines, U. S. Department of the Interior, pp 263-276.

Vat Leaching in the L-P-F (Leaching-Precipitation-Flotation) Process for Mixed Sulfide and Nonsulfide Ores

1. Function - Copper oxide minerals which are present in mixed ores are only partially amenable to concentration by the flotation process. The L-P-F (Leaching-Precipitation-Flotation) process developed to treat these mixed ores comprises three steps: (1) vat or percolation leaching with sulfuric acid to put the oxide minerals in the ore in solution, (2) precipitating the dissolved copper as cement copper (or alternatively transferring the pregnant leach solution to the electrolytic refining plant), and (3) recovery of the cement copper and copper sulfide minerals by flotation (Cement copper, like the sulfide minerals, is easily concentrated by flotation methods).

2. Input Materials - Ground "mixed" copper ore, dilute sulfuric acid, water.

3. Operating Parameters -

   Temperature: Ambient

   Pressure: Atmospheric

4. Utilities -

   Electric Energy; Pump: 0.2×10^8 joules/metric ton (5.5 kWhe/metric ton or 0.052×10^6 Btu/short ton) of ore (includes also associated agitated tank leaching residue washing-pumping energy)

5. Waste Streams -

   Possible leakage in spent leach solution ponds. Both the leaching liquid and the leached solids are further processed.

6. EPA Source Classification Code - None

7. References -

(1) Pings, W. B., and Rau, Earl L., Recent Trends in Copper Metallurgy, Mineral Industries Bulletin, Colorado School of Mines Research Foundation, Inc., Vol II, No. 4, July, 1968, pp 1-12.

(2) Private communication with BCL staff who have visited mines and consulted with producers.

(3) Wideman, F. L., Chapter on Copper, Mineral Facts and Problems, 1965 edition, Bureau of Mines, U. S. Department of the Interior, pp 263-276.

COPPER - MIXED SULFIDE AND NONSULFIDE
(OXIDE AND SILICATE) ORES

PROCESS NO. 14

Residue Washing of Ground Vat Leached Ore in the L-P-F (Leaching-Precipitation-Flotation) Process

1. Function - After the leaching cycle, copper in solution in dilute sulfuric acid is in contact with ground ore which still contains ground unreacted copper sulfide minerals. The ore is washed free of the copper leach by countercurrent washing.

2. Input Materials - water

3. Operating Parameters -

   Temperature: Ambient

   Pressure: Atmospheric

4. Utilities -

   Electric Energy: Pumping: 0.20×10^8 joules/metric ton (5.5 kWhe/metric ton or 0.052×10^6 Btu/short ton) of ore (includes energy required on vat leach solution and agitated tank leaching operations)

5. Waste Streams -

   Wash waters representing various stages of washing are stored in tanks. Possibility of spillage, leaks, etc.

6. EPA Source Classification Code - None

7. References -

   (1) Pings, W. B., and Rau, Earl L., Recent Trends in Copper Metallurgy, Mineral Industries Bulletin, Colorado School of Mines Research Foundation, Inc., Vol II, No. 4, July, 1968, pp 1-12.

   (2) Private communication with BCL staff who have visited mines and consulted with producers.

(3) Wideman, F. L., Chapter on Copper, Mineral Facts and Problems, 1965 edition, Bureau of Mines, U. S. Department of the Interior, pp 263-276.

Flotation of Reground Mixed Ore Residue After Vat Leaching and Washing

1. Function - The copper sulfide minerals remaining in the leached and washed residue are reground to free these minerals from any attached gangue and then separated from them by a "flotation" technique which depends on the differences in the surface characteristics between the sulfide mineral particles and the particles of gangue. The ground ore is agitated by rising air bubbles in cells containing water, various oils, and chemical reagents which cause the sulfide mineral particles to be selectively wetted by the oil present and become attached to the rising bubbles, whereupon they rise to the surface and are scraped off.

2. Input Materials - Reground washable residue from vat leaching, waters, oils, inorganic, and organic flotation reagents.

3. Operating Parameters - Flotation cells are operated at ambient temperature and pressure.

4. Utilities -

   Electric Energy: 0.23×10^8 joules/metric ton (6.5 kWhe/metric ton or 0.062×10^6 Btu/short ton) of ground ore input.

5. Waste Streams -

   Slurries containing tailings, reagent losses to tailings

   Solid tailings remaining after dewatering

6. EPA Source Classification Code - None

7. References -

(1) Pings, W. B., and Rau, Earl L., Recent Trends in Copper Metallurgy, Minerals Industries Bulletin, Colorado School of Mines Research Foundation, Inc., Vol II, No. 4, July, 1968, pp 1-12.

COPPER - MIXED SULFIDE AND NONSULFIDE (OXIDE AND SILICATE) ORES

PROCESS NO. 15

Agitated Tank Leaching of Slimes from the Classifier in the Grinding Circuits with Pregnant Leach Liquor from the Vat Leaching Operation in the L-P-F (Leaching-Precipitation-Flotation) Process

1. Function - Slimes produced in the course of grinding and regrinding would fill the interstices of the ground material in the leaching vat and prevent effective percolation of the leach liquor through the ground ore. To prevent this, and still obtain the copper values in very finely divided ore, the slimes are leached separately with the pregnant vat leaching liquor in an agitated tank leach.

2. Input Materials - Pregnant leach liquor from the vat leach and slimes from the classifiers in the grinding operations.

3. Operating Parameters -

   Temperature: Ambient

   Pressure: Ambient

4. Utilities -

   Electric Energy; Pumping -- includes vat leaching and residue washing 0.20×10^8 joules/metric ton (5.5 kWhe/metric ton or 0.052×10^6 Btu/short ton) of ore

5. Waste Streams -

   Both the leach liquor product and the leached slimes are further processed

   Spillage and leaks in equipment

6. EPA Source Classification Code - None

7. References -

   (1) Pings, W. B., and Rau, Earl L., Recent Trends in Copper Metallurgy, Minerals Industries Bulletin, Colorado School of Mines Research Foundation, Inc., Vol II, No. 4, July, 1968, pp 1-12.

(2) Private communication with BCL staff who have visited mines and consulted with producers.

(3) Wideman, F. L., Chapter on Copper, Mineral Facts and Problems 1965 edition, Bureau of Mines, U. S. Department of the Interior, pp 263-276.

Cementation of the Pregnant Liquor from the Agitation Leaching Operation in the L-P-F (Leaching-Precipitation-Flotation) Process

1. Function - The pregnant liquor from the agitated leaching tanks is mixed with sponge iron which precipitates the copper out of solution as cement copper; in a later step, the precipitated cement copper is separated and concentrated by flotation methods.

2. Input Materials - Pregnant leach solution and sponge iron

3. Operating Parameters -

   Temperature: Ambient

   Pressure: Atmospheric

4. Utilities -

   Electric Energy; Pumping--includes entire leaching and cementation processing cycle 0.20×10^8 joules/metric ton (5.5 kWhe/metric ton or 0.052×10^6 Btu/short ton) of ore. 0.15×10^8 joules/kilogram (4.3 kWhe/kilogram or 0.02×10^6 Btu/pound) of cement copper.

5. Waste Streams -

   Leakage and spillage from spent liquor ponds

   Solids are further processed

6. EPA Source Classification Code - None

7. References -

   (1) Pings, W. B., and Rau, Earl L., Recent Trends in Copper Metallurgy, Mineral Industries Bulletin, Colorado School of Mines Research Foundation, Inc., Vol II, No. 4, July, 1968, pp 1-12.

(2) Private communication with BCL staff who have visited mines and consulted with producers.

(3) Wideman, F. L., Chapter on Copper, Mineral Facts and Problems, 1965 edition, Bureau of Mines, U. S. Department of the Interior, pp 263-276.

COPPER - MIXED SULFIDES AND NONSULFIDES (OXIDE AND SILICATE) ORES

PROCESS NO. 6

Flotation of Cement Copper after Precipitation with Sponge Iron from Pregnant Agitated Leach Tank Liquor in the L-P-F (Leaching-Precipitation-Flotation) Process

1. Function - Cement copper from the precipitation process responds to flotation in much the same manner as sulfide minerals. Accordingly, it is concentrated by flotation methods. Usually it is mixed with the sulfide flotation product obtained from the vat leaching residue and shipped to the smelter.

2. Input Materials - Cement copper from precipitation operation, water, oils, and flotation reagents.

3. Operating Parameters - Flotation cells are operated at ambient temperature and pressure.

4. Utilities -

   Electric Energy: 0.23×10^{8} joules/metric ton (6.5 kWhe/metric ton or 0.062×10^{6} Btu/short ton) of ground ore input.

5. Waste Streams -

   Sturries containing tailings, reagent losses to tailings

   Solid tailings remaining after dewatering

6. EPA Source Classification Code - None

7. References -

(1) Pings, W. B., and Rau, Earl L., Recent Trends in Copper Metallurgy, Mineral Industries Bulletin, Colorado School of Mines Research Foundation, Inc., Vol II, No. 4, July, 1968, pp 1-12.

(2) Private communication with BCL staff who have visited mines and consulted with producers.

(3) Wideman, F. L., Chapter on Copper, Mineral Facts and Problems, 1965 edition, Bureau of Mines, U. S. Department of the Interior, pp 263-276.

Gold

The consumption of gold in the United States exceeds domestic production of this commodity by about five fold. U.S. reserves of gold are fairly large but of low grade so that production is not likely to equal consumption even with an intensified mining effort brought about by increasing gold prices. Most of the gold reserve in the U.S. is in lode deposits such as in the Homestake, South Dakota and Carlin, Nevada, ore bodies, but considerable gold also is in reserve in copper deposits as a dilute part of the mineralization. In fact, about half of the U.S. primary production of gold is as byproduct from copper ores.

When the rocks of a lode gold deposit are dissolved and disintegrated by "weathering" (i.e., rain, freezing, erosion, etc.), the gold particles resistant to these forces are liberated and washed into waterways. This is the so-called "placer" gold ore and is distinguished from "lode" ore in which the gold is still associated, encapsulated, etc., in other rocks.

Much of the gold recovered in the U.S. from both lode and placer mining operations is in the form of impure, but nevertheless, metallic gold. From placer operations the product may be a "heavy sand" concentrate which is very rich in metallic gold, or indeed from some placers, the product may be only metallic gold with attendent impurities (e.g., silver). Leaner ores from placers, or some of the higher gold content gangue material (i.e., middlings), may be sent through an amalgamation process to result in the end product, gold amalgam. Crude gold bullion may be obtained by retorting gold amalgam,which process liberates gold from the mercury of the amalgam. Lode gold ore concentration product may also be gold amalgam or gold bullion obtained from retorting amalgam.

The products of gold ore mining and concentrating are:

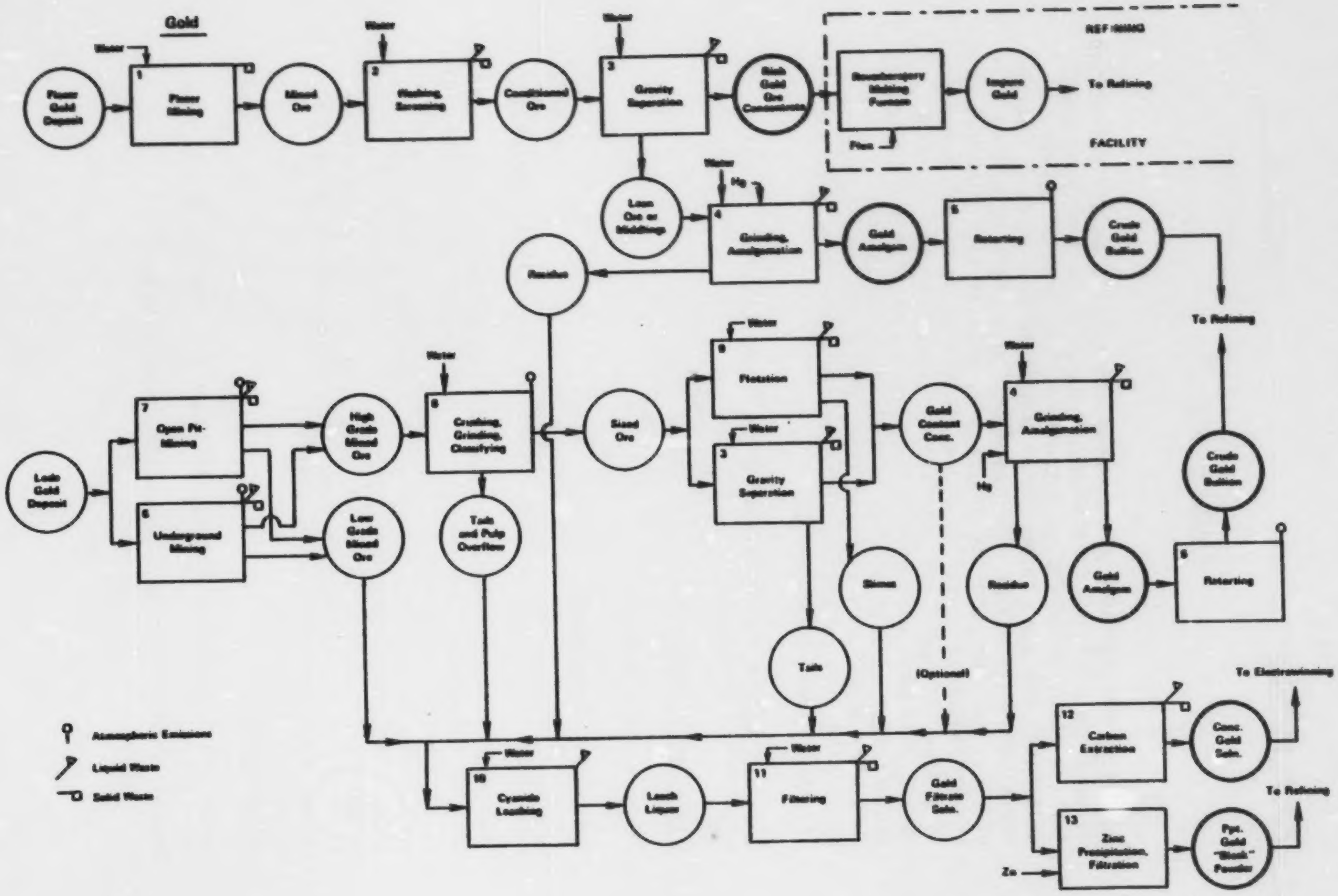
(a) Rich gold ore concentrate

(b) Gold amalgam or crude gold bullion from retorting amalgams

(c) Concentrated gold solutions

(d) "Black" powder, precipitated gold powder.

As previously stated, gold ores may be broadly categorized as placer and lode types. The mining methods used for the recovery of these are placer mining and conventional open pit or underground mining (for lode ores). Wet gravity methods of concentrating, flotation, leaching, and various solution extraction techniques are some of the processes additionally used in the recovery of gold. These methods are depicted in sequential order on the accompanying process flow diagram and are described in the following paragraphs. The numbers in the process blocks on the diagram are keyed to the corresponding process descriptive text.

Gold
Placer Gold Deposit
Water
1 Placer Mining
Mined Ore
Water
2 Washing, Screening
Conditioned Ore
Water
3 Gravity Separation
Rich Gold Ore Concentrate
Reverberatory Melting Furnace
Flux
Impure Gold
To Refining
REFINING
FACILITY
Lean Ore or Middlings
Water
Hg
4 Grinding, Amalgamation
Gold Amalgam
5 Retorting
Crude Gold Bullion
To Refining
Residue
Lode Gold Deposit
7 Open Pit Mining
6 Underground Mining
High Grade Mined Ore
Low Grade Mined Ore
Water
8 Crushing, Grinding, Classifying
Tails and Pulp Overflow
Sized Ore
Water
9 Flotation
Water
3 Gravity Separation
Gold Content Conc.
Slimes
Tails
(Optional)
Water
4 Grinding, Amalgamation
Hg
Residue
Gold Amalgam
5 Retorting
Crude Gold Bullion
Water
10 Cyanide Leaching
Leach Liquor
Water
11 Filtering
Gold Filtrate Soln.
12 Carbon Extraction
Conc. Gold Soln.
To Electrowinning
Zn
13 Zinc Precipitation, Filtration
Ppt. Gold "Black" Powder
To Refining
Atmospheric Emissions
Liquid Waste
Solid Waste

GOLD - PLACER DEPOSITS PROCESS NO. 1

Placer Mining

1. Function - Placer mining comprises the excavation and delivering of auriferous gravel from alluvial deposits to a washing plant for the recovery of its gold content. The type of deposit determines the particular placer mining method used: (1) large stream deposits may be mined by floating dredges combining digging, washing, gravity separation, and tailings disposal in a self contained unit, (2) hydraulic mining or gravel pumping is another method which consists of excavating and breaking up a gravel bank with hydraulic monitors, washing the disintegrated material into a sump, elevating this material to a line of sluice boxes with a gravel pump, where the gold is recovered by slucing, (3) Excavation by power shovel or dragline, and (4) small-scale hand methods.

2. Input Materials - Auriferrous gravel from alluvial deposits, water under pressure.

3. Operating Parameters -

   Temperature: Ambient

   Pressure: Atmospheric

4. Utilities - Includes washing, screening and gravity separation

   The amount of power used depends upon the method of placer mining and concentration. For dredging: 0.046×10^8 joules/metric ton (1.27 kWhe/metric ton or 0.012×10^6 Btu/short ton) of placer gravel for excavation, delivery, washing, and gravity concentration. For gravel pumping: 0.086×10^8 joules/metric ton (2.38 kWhe/metric ton or 0.023×10^6 Btu/short ton) of placer gravel for excavation, collection into sump, elevation to the sluice boxes, and concentration by sluicing.

5. Waste Streams -

   Water run from hydraulicking, tailings run from dredging, etc.

   Gravel remaining on tailings after concentration.

6. EPA Source Classification Code - None

7. References -

(1) Private communication with members of the BCL staff who have consulted with producers on energy requirements and specifics of operation.

(2) Ageton, R. W., Chapter on Gold, Mineral Facts and Problems, 1970; Bureau of Mines, U. S. Department of the Interior, Washington, D.C., pp 563-572.

(3) Ryan, J. Patrick; Chapter on Gold, Mineral Facts and Problems, 1965, Bureau of Mines Bulletin 630, Bureau of Mines, U. S. Department of the Interior, Washington, D.C., pp 387-397.

(4) Development Document for Effluent Guidelines and Standards of Performance, Ore Mining and Dressing Industry (Draft), U. S. Environmental Protection Agency, Washington, D.C. (Prepared by the Calspan Corp., Buffalo, N. Y.).

GOLD - PLACER DEPOSITS PROCESS NO. 2

Washing and Screening

1. Function - The function of washing and screening of auriferrous gravel is to separate sand, small rocks, heavy minerals, and gold from barren rock oversize by washing it through rotating cylindrical screens (washing trommels).

2. Input Materials - Auriferrous gravel and water

3. Operating Parameters -

   Temperature: Ambient

   Pressure: Atmospheric

4. Utilities - (Includes dredging and gravity separation)

   The amount of power used depends upon the method of placer mining and concentration. For dredging: 0.046×10^8 joules/metric ton (1.27 kWhe/metric ton or 0.012×10^6 Btu/short ton) of placer gravel for excavation, delivery, washing, and gravity concentration. For gravel pumping: 0.086×10^8 joules/metric ton (2.38 kWhe/metric ton or 0.023×10^6 Btu/short ton) of placer gravel for excavation, collection into a sump, elevation to the sluice boxes, and concentration by sluicing.

5. Waste Streams -

   Dust where trommeling is done dry as in some areas of the U.S. Southwest.

   Water emissions from washing trommel.

   Barren rock oversize from washing operations.

6. EPA Source Classification Code - None

7. References -

   (1) Private communication with members of the BCL staff who have consulted with producers on energy requirements and specifics of operation.

(2) Ageton, R. W., Chapter on Gold, Mineral Facts and Problems, 1970; Bureau of Mines, U. S. Department of the Interior, Washington, D.C., pp 563-572.

(3) Ryan, J. Patrick; Chapter on Gold, Mineral Facts and Problems, 1965, Bureau of Mines Bulletin 630, Bureau of Mines, U. S. Department of the Interior, Washington, D.C., pp 387-397.

(4) Development Document for Effluent Guidelines and Standards of Performance, Ore Mining and Dressing Industry (Draft), U. S. Environmental Protection Agency, Washington, D.C. (Prepared by the Calspan Corp., Buffalo, N. Y.).

GOLD - PLACER DEPOSITS PROCESS NO. 3

Gravity Separation

1. Function - Gold, with its high density, is easily separated from the lighter weight gravel by gravity concentration methods; these include sluice boxes operated in conjunction with placer mining, and jigs and tables.

2. Input Materials - Auriferrous gravel from alluvial deposits, water under pressure.

3. Operating Parameters -

   Temperature: Ambient

   Pressure: Atmospheric

4. Utilities - (Includes dredging, washing and screening)

   The amount of power used depends upon the method of placer mining and concentration. For dredging: 0.046 x 10^8 joules/metric ton (1.27 kWhe/metric ton or 0.012 x 10^6 Btu/short ton) of placer gravel for excavation, delivery, washing, and gravity concentration. For gravel pumping: 0.086 x 10^8 joules/metric ton (2.38 kWhe/metric ton or 0.023 x 10^6 Btu/short ton) of placer gravel for excavation, collection into a sump, elevation to the sluice boxes, and concentration by sluicing.

5. Waste Streams -

   Dusting in areas of U.S. Southwest where air, rather than water, pulsations are used in dry gravity-concentration processes

   Barren gravel waste from gravity concentration

6. EPA Source Classification Code - None

7. References -

   (1) Private communication with members of the BCL staff who have consulted with producers on energy requirements and specifics of operation.

(2) Ageton, R. W., Chapter on Gold, Mineral Facts and Problems, 1970; Bureau of Mines, U. S. Department of the Interior, Washington, D.C., pp 563-572.

(3) Ryan, J. Patrick; Chapter on Gold, Mineral Facts and Problems, 1965, Bureau of Mines Bulletin 630, Bureau of Mines, U. S. Department of the Interior, Washington, D.C., pp 387-397.

(4) Development Document for Effluent Guidelines and Standards of Performance, Ore Mining and Dressing Industry (Draft), U. S. Environmental Protection Agency, Washington, D.C. (Prepared by the Calspan Corp., Buffalo, N. Y.).

GOLD - PLACER DEPOSITS PROCESS NO. 4

Grinding and Amalgamation

1. Function - Current practice (in the single mill in Colorado which uses an amalgamation process) involves crushing and grinding of lode ore, separation of the gold-bearing black sands by jigging, and final concentration of the gold in the sands by batch amalgamation with mercury in a barrel amalgamator. In barrel amalgamation, the ore is gently ground in a cylindrical rod or ball mill for several hours to bring the gold and mercury into intimate contact. The resulting amalgam is collected in a gravity trap.

2. Input Materials - Ground ore from a gold bearing lode deposit, mercury and water.

3. Operating Parameters -

   Temperature: Ambient

   Pressure: Atmospheric

4. Utilities -

   Electric Energy: crushing and grinding; 0.56 x 10^8 joules/metric ton (15 kWhe/metric ton or 0.15 x 10^6 Btu/short ton) of ore.

5. Waste Streams -

   Water containing suspended solids from amalgamation plant to tailing pond (copper, iron, mercury, and zinc in solution)

6. EPA Source Classification Code - None

7. References -

   (1) Private communication with members of the BCL staff who have consulted with producers on energy requirements and specifics of operation.

   (2) Ageton, R. W., Chapter on Gold, Mineral Facts and Problems, 1970; Bureau of Mines, U. S. Department of the Interior, Washington, D.C., pp 563-572.

(3) Ryan, J. Patrick; Chapter on Gold, Mineral Facts and Problems, 1965, Bureau of Mines Bulletin 630, Bureau of Mines, U. S. Department of the Interior, Washington, D.C., pp 387-397.

(4) Development Document for Effluent Guidelines and Standards of Performance, Ore Mining and Dressing Industry (Draft), U. S. Environmental Protection Agency, Washington, D.C. (Prepared by the Calspan Corp., Buffalo, N. Y.)

Retorting

1. Function - Gold dissolved in mercury is recovered by distilling off the mercury in a retort.

2. Input Materials - Gold amalgam

3. Operating Parameters -

   The retort is heated to vaporize the mercury constituent [b.p. 357 C (675 F)]. The pressure is atmospheric.

4. Utilities -

   The heat required is relatively low since only small amounts of gold and mercury are handled relative to the amount of ore mined. Fuel to supply heat is usually transported to the site.

5. Waste Streams -

   Mercury emissions

6. EPA Source Classification Code - None

7. References -

(1) Private communication with members of the BCL staff who have consulted with producers on energy requirements and specifics of operation.

(2) Ageton, R. W., Chapter on Gold, Mineral Facts and Problems, 1970; Bureau of Mines, U. S. Department of the Interior, Washington, D.C., pp 563-572.

(3) Ryan, J. Patrick; Chapter on Gold, Mineral Facts and Problems, 1965, Bureau of Mines Bulletin 630, Bureau of Mines, U. S. Department of the Interior, Washington, D.C., pp 387-397.

(4) Development Document for Effluent Guidelines and Standards of Performance, Ore Mining and Dressing Industry (Draft), U. S. Environmental Protection Agency, Washington, D.C. (Prepared by the Calspan Corp., Buffalo, N. Y.).

Underground Mining

1. Function - Underground mining involves the removal of ores from deep deposits by a number of techniques, the selection of which depends on the characteristics of the ore body. There are two main methods, caving and supported stoping. Caving methods used in the mining of gold include block caving used in large, homogeneous, structurally weak ore bodies, and top-slicing for smaller and more irregular ore bodies. Supported stoping methods are used to mine veins and flat deposits of gold. There are two types, naturally supported stoping methods include open stoping for small ore bodies and open stoping with natural pillar support for wider ore bodies, both of which have structurally strong foot walls (floors in bedded deposits) and hanging walls (roofs in bedded deposits). Artificially supported stoping methods include shrinkage stoping for steeply dipping tabular-shaped deposits having fairly strong foot and hanging walls, and little waste; cut and fill stoping for similarly shaped deposits having weak walls; and timbered or square-set stoping methods for cases where the ore is weak and the surrounding rock is so weak that temporary timbered support is necessary as an interim measure prior to filling with broken waste rock.

2. Input Materials - Nitroglycerine explosives (dynamite). About 0.5 kg/metric ton (1 lb/short ton) of ore mined.

3. Operating Parameters -

   Temperature: Ambient

   Pressure: Atmospheric

4. Utilities -

   Electric Energy: Amount used varies widely dependong upon method of mining and type of ore body. Mean value estimated to be about 0.32×10^8 joules/metric ton (9 kWhe/metric ton or 0.086×10^6 Btu/short ton) of ore.

5. Waste Streams -

Mine water effluent

Storage of solid gangue

6. EPA Source Classification Code - None

7. References -

(1) U. S. Census of Mineral Industries, Major Group 10(Copper, lead, zinc, gold, and silver ores) Table 3A, p 10B-11; Table 7, pp 10-22.

(2) Private communication with members of the BCL staff who have consulted with producers on energy requirements and specifics of operation.

(3) Ageton, R. W., Chapter on Gold, Mineral Facts and Problems, 1970; Bureau of Mines, U. S. Department of the Interior, Washington, D.C., pp 563-572.

(4) Ryan, J. Patrick; Chapter on Gold, Mineral Facts and Problems, 1965, Bureau of Mines Bulletin 630, Bureau of Mines, U. S. Department of the Interior, Washington, D.C., pp 387-397.

(5) Development Document for Effluent Guidelines and Standards of Performance, Ore Mining and Dressing Industry (Draft), U. S. Environmental Protection Agency, Washington, D.C. (Prepared by the Calspan Corp., Buffalo, N. Y.).

Open-Pit Mining

1. **Function** - Open-pit mining involves the removal of ore from deposits at or near the surface by a cycle of operations consisting of drilling blast holes, blasting the ore, loading the broken ore onto trucks or rail cars, and transporting it to the concentrators. (In a few cases, blasting is not required; ore is "ripped" by bulldozers and loaded.) Barren surface rock overlaying the deposit must be removed to uncover the ore body; such overburden may be up to (and, in one case, even exceeding) 152 meters (500 feet) thick.

2. **Input Materials** - Explosives (ammonium nitrate-fuel oil) 0.55 kg/metric ton (1.1/short ton) of material mined.

3. **Operating Parameters** -

   Temperature: Ambient

   Pressure: Atmospheric

4. **Utilities** -

   Diesel Fuel: 63 liters/metric ton (15.0 gal/short ton) of ore

   Equivalent Energy: 2.2×10^8 joules/metric ton (206×10^3 Btu/short ton) of ore.

5. **Waste Streams** -

   Airborne particulates from blasting

   No water runoff in the only open-pit gold mine in the U.S. (Nevada, desert climate)

   Stockpiling of overburden

6. **EPA Source Classification Code** - None

7. **References** -

   (1) Private communication with members of the BCL staff who have consulted with producers on energy requirements and specifics of operation.

(2) Ageton, R. W., Chapter on Gold, Mineral Facts and Problems, 1970; Bureau of Mines, U. S. Department of the Interior, Washington, D.C., pp 563-572.

(3) Ryan, J. Patrick; Chapter on Gold, Mineral Facts and Problems, 1965, Bureau of Mines Bulletin 630, Bureau of Mines, U. S. Department of the Interior, Washington, D.C., pp 387-397.

(4) Development Document for Effluent Guidelines and Standards of Performance, Ore Mining and Dressing Industry (Draft), U. S. Denvironmental Protection Agency, Washington, D.C. (Prepared by the Calspan Corp., Buffalo, N. Y.).

Crushing, Grinding, and Classifying

1. Function - If ore is to be concentrated by flotation or gravity separation, it must be ground to a fineness sufficient to liberate the valuable minerals from the associated gangue. To accomplish this, it is usually crushed at the mine site to an intermediate size for subsequent handling in the grinding operation at the mill. Grinding is done in ball mills or rod mills with a classifier in the circuit to separate and return ground oversize ore to the grinding mills.

2. Input Materials - Ore and water to the grinding mills and classifiers

3. Operating Parameters - Crushing is a separate operation, usually done dry. Grinding is usually done wet in a closed circuit with a classifier.

   Temperature: Ambient

   Pressure: Atmospheric

4. Utilities -

   Crushing: 0.11×10^8 joules/metric ton (3.1 kWhe/metric ton or 0.029×10^6 Btu/short ton) of ore

   Grinding and Classifying: 0.56×10^8 joules/metric ton (15.4 kWhe/metric ton or 0.15×10^6 Btu/short ton) of ore

5. Waste Streams -

   Dust, particulates from the crushing operation

   Water, effluents from grinding

   Waste rock (associated with crushing operation at mine shaft)

6. EPA Source Classification Code - None

7. References -

(1) Private communication with members of the BCL staff who have consulted with producers on energy requirements and specifics of operation.

(2) Ageton, R. W., Chapter on Gold, Mineral Facts and Problems, 1970, Bureau of Mines, U. S. Department of the Interior, Washington, D.C., pp 563-572.

(3) Ryan, J. Patrick; Chapter on Gold, Mineral Facts and Problems, 1965, Bureau of Mines Bulletin 630, Bureau of Mines, U. S. Department of the Interior, Washington, D.C., pp 387-397.

(4) Development Document for Effluent Guidelines and Standards of Performance, Ore Mining and Dressing Industry (Draft), U. S. Evnrionmental Protection Agency, Washington, D.C. (Prepared by the Calspan Corp., Buffalo, N. Y.).

Flotation

1. Function - The flotation technique may be used to separate ground ore mineral particles from gangue mineral particles and from each other in complex ores if the differences in the surface characteristics between the various ore mineral and gangue particles are sufficiently large. In the flotation process, the ground ore is agitated by rising air bubbles in cells containing water, various oils, and chemical reagents which cause the mineral particle to be selectively wetted by the oil present and become attached to the rising air bubbles, whereupon they rise to the surface of the cell and are scraped off. In complex ores containing more than one ore mineral value, reagents called depressants are used to "depress" one type mineral particle while the other is being floated.

2. Input Materials - Ground ore, water, oils, inorganic, and organic flotation reagents.

3. Operating Parameters - Flotation cells are operated at ambient temperature and pressure.

4. Utilities -

   Electric Energy: 0.24×10^8 joules/metric ton (6.6 kWhe/metric ton or 0.063×10^6 Btu/short ton) ground ore input

5. Waste Streams -

   Slurries containing tailings, reagent losses to tailings

   Solid tailings remaining after dewatering

6. EPA Source Classification Code - None

7. References -

   (1) Private communication with members of the BCL staff who have consulted with producers on energy requirements and specifics of operation.

(2) Ageton, R. W., Chapter on Gold, Mineral Facts and Problems, 1970, Bureau of Mines, U. S. Department of the Interior, Washington, D.C., pp 563-572.

(3) Ryan, J. Patrick, Chapter on Gold, Mineral Facts and Problems, 1965, Bureau of Mines Bulletin 630, Bureau of Mines, U. S. Department of the Interior, Washington, D.C., pp 387-397.

(4) Development Document for Effluent Guidelines and Standards of Performance, Ore Mining and Dressing Industry (Draft), U. S. Environmental Protection Agency, Washington, D.C. (Prepared by the Calspan Corp., Buffalo, N. Y.).

Gravity Separation

1. Function - Gold, with its high density, is easily separated from the lighter weight gangue by gravity concentration. Accordingly, practice on lode ores containing sulfides of lead, zinc, and copper, in addition to native gold (and silver) is to make a prior gravity separation of native gold (and silver) in the ground ore by jigging (gold in finely ground ore also can be gravity-concentrated by tabling). Gold, separated in this manner, can be recovered by amalgamation, or alternatively, by cyanidation methods. After the precious metals are recovered, the jig concentrate is sent to a flotation circuit for the separation of other metal sulfide mineral particles.

2. Input Materials - Ground ore from the grinding circuits

3. Operating Parameters -

   Temperature: Ambient

   Pressure: Atmospheric

4. Utilities -

   Electric Energy: (Jigs or tables) Very low on a per-ton-of-ore basis

5. Waste Streams -

   Slurried ore solids

   Mercury contaminants from losses in the amalgamation circuit

   Heavy metals and cyanide dissolved in tailing pond effluent in plants using cyanidation recovery processes, cyanide could also accidentally be lost in an accidental discharge from the flotation machines

6. EPA Source Classification Code - None

7. References -

(1) Private communication with members of the BCL staff who have consulted with producers on energy requirements and specifics of operation.

(2) Ageton, R. W., Chapter on Gold, Mineral Facts and Problems, 1970, Bureau of Mines, U. S. Department of the Interior, Washington, D.C., pp 563-572.

(3) Ryan, J. Patrick; Chapter on Gold, Mineral Facts and Problems, 1965, Bureau of Mines Bulletin 630, Bureau of Mines, U. S. Department of the Interior, Washington, D.C., 387-397.

(4) Development Document for Effluent Guidelines and Standards of Performance, Ore Mining and Dressing Industry (Draft), U. S. Environmental Protection Agency, Washington, D.C. (Prepared by the Calspan Corp., Buffalo, N. Y.).

Grinding and Amalgamation

1. Function - Current practice (in the single mill in Colorado which uses an amalgamation process) involves crushing and grinding of lode ore separation of the gold-bearing black sands by jigging, and final concentration of the gold in the sands by batch amalgamation in a barrel amalgamator. In barrel amalgamation, the ore is gently ground in a cylindrical rod or ball mill for several hours to bring the gold and mercury into intimate contact. The resulting amalgam is collected in a gravity trap.

2. Input Materials - Ground ore from a gold bearing lode deposit.

3. Operating Parameters -

   Temperature: Ambient

   Pressure: Atmospheric

4. Utilities -

   Electric Energy: 0.56 x 10^8 joules/metric ton (15 kWhe/metric ton or 0.15 x 10^6 Btu/short ton) of ore

5. Waste Streams -

   Water containing suspended solids from amalgamation plant to tailing pond (copper, iron, mercury, and zinc in solution)

6. EPA Source Classification Code - None

7. References -

   (1) Private communication with members of the BCL staff who have consulted with producers on energy requirements and specifics of operation.

   (2) Ageton, R. W., Chapter on Gold, Mineral Facts and Problems, 1970, Bureau of Mines, U. S. Department of the Interior, Washington, D.C., pp 563-572.

(3) Ryan, J. Patrick, Chapter on Gold, Mineral Facts and Problems, 1965, Bureau of Mines Bulletin 630, Bureau of Mines, U. S. Department of the Interior, Washington, D.C., pp 387-397.

(4) Development Document for Effluent Guidelines and Standards of Performance, Ore Mining and Dressing Industry (Draft), U. S. Environmental Protection Agency, Washington, D.C. (Prepared by the Calspan Corp., Buffalo, N. Y.).

Retorting

1. Function - Gold dissolved in mercury is recovered by distilling off the mercury in a retort.

2. Input Materials - Gold amalgam

3. Operating Parameters -

   The retort is heated to vaporize the mercury constituent [b.p. 357 C (675 F)]. The pressure is atmospheric.

4. Utilities -

   The heat required is relatively low since only small amounts of gold and mercury are handled relative to the amount of ore mined.

5. Waste Streams -

   Mercury emissions

6. EPA Source Classification Code - None

7. References -

   (1) Private communication with members of the BCL staff who have consulted with producers on energy requirements and specifics of operation.

   (2) Ageton, R. W., Chapter on Gold, Mineral Facts and Problems, 1970, Bureau of Mines, U. S. Department of the Interior, Washington, D.C., pp 563-572.

   (3) Ryan, J. Patrick, Chapter on Gold, Mineral Facts and Problems, 1965, Bureau of Mines Bulletin 630, Bureau of Mines, U. S. Department of the Interior, Washington, D.C., pp 387-397.

   (4) Development Document for Effluent Guidelines and Standards of Performance, Ore Mining and Dressing Industry (Draft), U. S. Environmental Protection Agency, Washington, D.C. (Prepared by the Calspan Corp., Buffalo, N. Y.).

Cyanide Leaching

1. Function - Cyanidation leaching of gold ore is done by four methods in the United States. For low-grade ores, and for recovery of old mine waste dumps, heap leaching is used. For high-grade ores, vat leaching, agitation leaching, and carbon-cyanidation are used (in the carbon-cyanidation process, the solubilized gold cyanide is first collected by adsorption onto activated charcoal and then stripped with hot caustic).

2. Input Materials - Low-grade ore (old mine dumps) in the case of heap leaching; higher grade ground ore in the case of vat, agitation and charcoal-cyanidation leaching, cyanide, and water.

3. Operating Parameters -

   Usually at ambient temperature and pressure.

4. Utilities -

   Electric Energy: Pumping, 0.12×10^8 joules/metric ton (3.3 kWhe/metric ton or 0.032×10^6 Btu/short ton) of ore

   Diesel Fuel Oil: For ore transfer, 1.8 liters/metric ton (0.48 gal/short ton) of ore

5. Waste Streams -

   Waste water from heap leaching containing large amounts of suspended solids. It also may contain mercury or cyanide.

   Waste water from other types of leaching of ground ore have high dissolved heavy metal concentrations, a high concentration of suspended solids, and dissolved reagents lost in the mill beneficiation processes. Cyanide and mercury are the most prominent.

   Solid wastes remaining after leaching

6. EPA Source Classification Code - None

7. References -

(1) Private communication with members of the BCL staff who have consulted with producers on energy requirements and specifics of operation.

(2) Ageton, R. W., Chapter on Gold, Mineral Facts and Problems, 1970, Bureau of Mines, U. S. Department of the Interior, Washington, D.C., pp 563-572.

(3) Ryan, J. Patrick, Chapter on Gold, Mineral Facts and Problems, 1965, Bureau of Mines Bulletin 630, Bureau of Mines, U. S. Department of the Interior, Washington, D.C., pp 387-397.

(4) Development Document for Effluent Guidelines and Standards of Performance, Ore Mining and Dressing Industry (Draft), U. S. Environmental Protection Agency, Washington, D.C. (Prepared by the Calspan Corp., Buffalo, N. Y.).

Filtering

1. **Function** - Leaching dissolves gold as a cyanide compound in the dilute cyanide solution. After the leaching step is completed, the cyanide pulp is washed and decanted in a series of thickeners, and the supernatent solution from the thickeners is clarified by pressure filtering, after which the dissolved gold is extracted either by zinc precipitation, or absorption of the solubilized gold cyanide on activated carbon, followed by stripping with hot caustic. Only a small volume of hot caustic is necessary to strip the gold from the charcoal.

2. **Input Materials** - Gold-bearing cyanide solutions, wash water, zinc and caustic

3. **Operating Parameters** -

   Temperature: Ambient

   Pressure: As high as 34 kg (75 lb) are used in pressure filters for classifying solutions

4. **Utilities** -

   Electric Energy: 0.01 x 10^8 joules/metric ton (0.28 kWhe/metric ton or 0.003 x 10^6 Btu/short ton) of treated ore

5. **Waste Streams** -

   The solution passes onto the precipitation step. Water required to wash and remove filter cake.

   Solid filter cake entrained in the filtering medium (removed by washing)

6. **EPA Source Classification Code** - None

7. **References** -

   (1) Private communication with members of the BCL staff who have consulted with producers on energy requirements and specifics of operation.

(2) Ageton, R. W., Chapter on Gold, Mineral Facts and Problems, 1970, Bureau of Mines, U. S. Department of the Interior, Washington, D.C., pp 563-572.

(3) Ryan, J. Patrick, Chapter on Gold, Mineral Facts and Problems, 1965, Bureau of Mines Bulletin 630, Bureau of Mines, U. S. Department of the Interior, Washington, D.C., pp 387-397.

(4) Development Document for Effluent Guidelines and Standards of Performance, Ore Mining and Dressing Industry (Draft), U. S. Environmental Protection Agency, Washington, D.C. (Prepared by the Calspan Corp., Buffalo, N. Y.).

Carbon Extraction

1. Function - This process, as currently used in the United States, treats only the slimes in the overflow from a cyclone classifier in the grinding circuit (the coarser underflow is vat leached and precipitated with zinc). Slimes in the overflow are mixed with cyanide solution in large tanks and agitated. It is then passed through a series of vats where the solubilized gold cyanide is collected by adsorption on activated charcoal held on screens. Gold is stripped from the charcoal with small amounts of hot caustic.

2. Input Materials - Overflow from the cyclone classifier

3. Operating Parameters - Hot caustic solutions are used to desorb the loaded carbon.

4. Utilities -

   Electric Energy: Pumping, (usage estimated to be about the same as for classification and precipitation with zinc) - 0.01×10^8 joules/metric ton (0.28 kWhe/metric ton or 0.003×10^6 Btu/short ton) of ore treated.

5. Waste Streams -

   Cyanide solution is recycled, hence the amount present in effluent is reduced.

   Slurried ore solids in tailing ponds

6. EPA Source Classification Code - None

7. References -

   (1) Private communication with members of the BCL staff who have consulted with producers on energy requirements and specifics of operation.

   (2) Ageton, R. W., Chapter on Gold, Mineral Facts and Problems, 1970, Bureau of Mines, U. S. Department of the Interior, Washington, D.C., pp 563-572.

(3) Ryan, J. Patrick, Chapter on Gold, Mineral Facts and Problems, 1965, Bureau of Mines Bulletin 630, Bureau of Mines, U. S. Department of the Interior, Washington, D.C., pp 387-397.

(4) Development Document for Effluent Guidelines and Standards of Performance, Ore Mining and Dressing Industry (Draft), U. S. Environmental Protection Agency, Washington, D.C. (Prepared by the Calspan Corp., Buffalo, N. Y.).

Zinc Precipitation, Filtration

1. Function - Gold is precipitated from pregnant cyanide leach solutions with zinc dust. The precipitate is collected in a filter press and the spent cyanide filtrate is recycled (with additions of cyanide to bring it up to leaching strength).

2. Input Materials - Pregnant leach solution and zinc dust.

3. Operating Parameters -

   Temperature: Ambient

   Pressure: Atmospheric

4. Utilities -

   Electric Energy: Pumping, (estimated from analogous pumping costs from pressure filtering) - 0.01 x 10^8 joules/metric ton (0.28 kWhe/metric ton or 0.003 x 10^6 Btu/short ton) of ore

5. Waste Streams -

   Filtrate is recycled, losses only

   Gold precipitate is valuable, losses are therefore small.

6. EPA Source Classification Code - None

7. References -

   (1) Private communication with members of the BCL staff who have consulted with producers on energy requirements and specifics of operation.

   (2) Ageton, R. W., Chapter on Gold, Mineral Facts and Problems, 1970, Bureau of Mines, U. S. Department of the Interior, Washington, D.C., pp 563-572.

(3) Ryan, J. Patrick, Chapter on Gold, Mineral Facts and Problems, 1965, Bureau of Mines Bulletin 630, Bureau of Mines, U. S. Department of the Interior, Washington, D.C., pp 387-397.

(4) Development Document for Effluent Guidelines and Standards of Performance, Ore Mining and Dressing Industry (Draft), U. S. Environmental Protection Agency, Washington, D.C. (Prepared by the Calspan Corp., Buffalo, N. Y.).

Iron

The iron ore industry of the United States grew from an annual output of less than 5 million tons in 1870 to over 115 million tons annually in 1951. Since that time, production has declined to about 90 million tons a year, of which about 83 percent is from the Lake Superior region. Approximately 40 million tons of ore per year are imported--that is, about one-third of the total amount consumed.

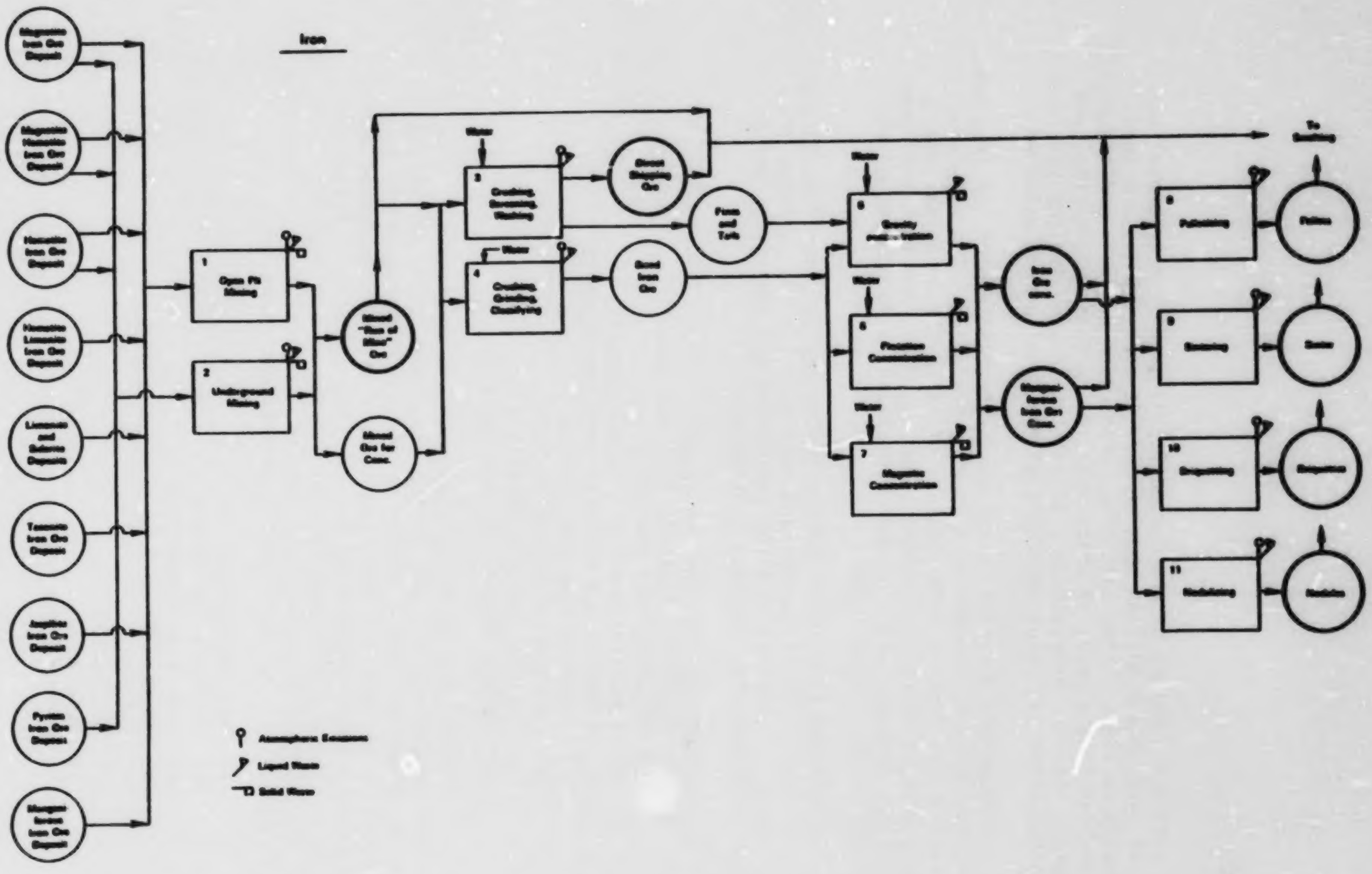
The Lake Superior district is the big production center for iron ore, producing about 83 percent of all crude ore mined. The remaining production was from 17 other States, of which the principal producers were California, Missouri, Wyoming, Utah, New York and Pennsylvania. Open pit mines produce approximately 90 percent of the iron ore in the United States.

The iron ore deposits of the United States may be classified on the basis of their mineral content and rock type for the purposes of this report. Accordingly, eight categories are identified which characterize domestic deposits. These are:

(a) Magnetite iron ore deposit
(b) Magnetite-hematite iron ore deposit
(c) Hematite iron ore deposit
(d) Hematite-limonite iron ore deposit
(e) Limonite and siderite iron ore deposits
(f) Taconite iron ore deposit
(g) Jaspilite Iron ore deposit
(h) Pyrites iron ore deposit
(i) Manganiferous iron ore deposit.

Most of the iron ores currently recovered are beneficiated to an iron ore concentrate and most of the concentrates are pelletized prior to shipment. Today, sintering is used almost entirely in connection with iron ore smelting and is usually accomplished within a relatively short distance of the smelting operation. Briquetting and nodulizing are infrequently used methods of agglomerating iron ores resulting in briquettes and nodules, respectively. In summary, the products that can be shipped from the iron mines are:

(a) Run-of-mine ore
(b) Direct shipping ore
(c) Iron ore concentrate
(d) Manganiferous iron ore concentrate
(e) Pellets
(f) Briquettes
(g) Nodules
(h) Sinter (cake).


Iron
Magnetite Iron Ore Deposit
Magnetite Hematite Iron Ore Deposit
Hematite Iron Ore Deposit
Hematite Limonite Iron Ore Deposit
Limonite and Siderite Deposits
Taconite Iron Ore Deposit
Jaspilite Iron Ore Deposit
Pyritic Iron Ore Deposit
Manganiferous Iron Ore Deposit
1 Open Pit Mining
2 Underground Mining
Mined "Run of Mine" Ore
Mined Ore for Conc.
Water
3 Crushing, Screening, Washing
Water
4 Crushing, Grinding, Classifying
Direct Shipping Ore
Fines and Tails
Sized Iron Ore
Water
5 Gravity Concentration
Water
6 Flotation Concentration
Water
7 Magnetic Concentration
Iron Ore Conc.
Manganiferous Iron Ore Conc.
To Smelting
8 Pelletizing
9 Sintering
10 Briquetting
11 Nodulizing
Pellets
Sinter
Briquettes
Nodules
Atmospheric Emissions
Liquid Waste
Solid Waste

Open Pit Mining

1. **Function** - Open pit mining involves the removal of ore from deposits at or near the surface by a cycle of operations consisting of drilling blast holes, blasting the ore, loading the broken ore onto trucks, skips, or rail cars, and transporting it to the concentrators. (In a few cases, blasting is not required; ore is "ripped" by bulldozers and loaded.) Barren surface rock overlaying the deposit must be removed to uncover the ore body.

2. **Input materials** - Explosives (ammonium-nitrate-fuel oil) 0.35 kg/metric ton (0.7 lb/short ton) of ore

3. **Operating Parameters** -

   Temperature: Ambient

   Pressure: Atmospheric

4. **Utilities** -

   Electrical Energy: 0.90×10^8 joules/metric ton (27.5 kWhe/metric ton or 0.26×10^6 Btu/short ton) of ore
   Diesel Fuel: 0.71 liters/metric ton (0.17 gal/short ton) of ore

5. Waste Streams -

   Airborne particulates from blasting and loading

   Waste water from the mine containing suspended solids and dissolved materials, oil, and grease

   Storage of overburden and runoff from it

6. **EPA Source Classification Code** - None

7. **References** -

   (1) Private communication with BCL staff who have visited producers.

   (2) Development Document for Effluent Guidelines and Standards of Performance, Ore Mining and Dressing Industry (Draft), U. S. Environmental Protection Agency, Washington, D.C. (prepared by the Calspan Corp., Buffalo, N. Y.), April 1975.

(3) Reno, Horace T., Chapter on Iron, Mineral Facts and Problems, 1965, Bureau of Mines Bulletin 630, Bureau of Mines, U.S. Department of the Interior, Washington, D.C., pp 455-479.

(4) Reno, Horace T., and Brantley, Francis E., Chapter on Iron, Mineral Facts and Problems, 1970, Bureau of Mines Bulletin 650, Bureau of Mines, U.S. Department of the Interior, Washington, D.C., pp 291-314.

(5) U.S. Steel Corp., (MacGannon, Harold E., Editor) The Making, Shaping, and Treating of Steel, 9th Ed., 1971, U.S. Steel Corp., Pittsburgh, PA, 1420 pp.

Underground Mining

1. **Function** - Underground methods are used to extract iron ore only where the cost of stripping is too high for economical open pit mining. The technique consists of sinking vertical shafts adjacent to the deposits far enough removed to avoid the effects of surface subsidence resulting from mining operations.

   Sublevel caving has been the principal underground method of mining iron ore in the Lake Superior district. Block and panel caving and variations thereof are used in large ore bodies where dilution is not a problem. Shrinkage stoping, open stoping, sublevel stoping, with many modifications and various other methods also are used depending on the size, shape, and character of the orebody, and the character of the enclosing rocks. Most bedded deposits are mined by room and pillar methods similar to those used in coal mining.

2. **Input Materials** - Explosives, ammonium nitrate and fuel oil, ammonium nitrate-TNT slurries, and gelatin dynamites are used.

3. **Operating Parameters** -

   Temperature: Ambient

   Pressure: Atmospheric

4. **Utilities** (Based on usage in a Michigan underground iron mine) -

   Electrical Energy: 1.3×10^8 joules/metric ton (37 kWhe/metric ton or 0.35×10^6 Btu/short ton of ore
   Natural Gas: (0.8 steres, 28 cu ft): 0.87 cu meters/metric ton (28 cu ft/short ton) of ore
   Diesel Fuel: (0.18 liters, 0.045 gal): 0.19 liters/metric ton (0.045 gal/short ton) of ore
   Gasoline: (0.03 liters, 0.008 gal): 0.033 liter/metric ton (0.008 gal/short ton) of ore

5. Waste Streams -

Waste water from the mine containing suspended solids, dissolved material, oil, and grease

Storage of waste rock from shafts and cuts to the ore body

6. EPA Source Classification Code - None

7. References -

(1) Private communication with BCL staff who have visited producers.

(2) *Development Document for Effluent Guidelines and Standards of Performance, Ore Mining and Dressing Industry* (Draft), U. S. Environmental Protection Agency, Washington, D.C. (prepared by the Calspan Corp., Buffalo, N. Y.), April 1975.

(3) Reno, Horace T., *Chapter on Iron*, Mineral Facts and Problems, 1965, Bureau of Mines Bulletin 630, Bureau of Mines, U. S. Department of the Interior, Washington, D.C., pp 455-479.

(4) Reno, Horace T., and Brantley, Francis E., *Chapter on Iron*, Mineral Facts and Problems, 1970, Bureau of Mines Bulletin 650, Bureau of Mines, U. S. Department of the Interior, Washington, D.C., pp 291-314.

(5) U.S. Steel Corp. (MacGannon, Harold E., Editor) *The Making, Shaping, and Treating of Steel*, 9th Ed., 1971, U.S. Steel Corp., Pittsburgh, PA, 1420 pp.

Crushing, Washing, and Screening

1. Function - Direct shipping ore requires only crushing, screening, and washing (to remove fine clay and sand) prior to shipment to the steel mills. High-grade, hard lump ore is crushed to about 20 cm (8 inches) if destined for use in an open-hearth furnace and a maximum of 10 cm (4 inches) if destined for use in a blast furnace. Practice is to remove minus 0.64 cm (1/4-inch) material. Minus 0.64 cm (1/4-inch) material either is sold at a discount or agglomerated.

2. Input Materials - Iron ore from the mine and water

3. Operating Parameters -

   Temperature: Ambient

   Pressure: Atmospheric

4. Utilities -

   Electrical Energy: for crushing, 0.51×10^8 joules/metric ton (14.1 kWhe/metric ton or 0.13×10^6 Btu/short ton) or ore; for pumpnng, 0.19×10^8 joules/metric ton (5.3 kWhe/metric ton or 0.050×10^6 Btu/short ton) of ore

5. Waste Streams -

   Dissolved and suspended solids in wash water which is clarified. Water is then recycled. Some losses.

6. EPA Source Classification Code - None

7. References -

(1) Private communication with BCL staff who have visited producers.

(2) Development Document for Effluent Guidelines and Standards of Performance, Ore Mining and Dressing Industry (Draft), U. S. Environmental Protection Agency, Washington, D.C. (prepared by the Calspan Corp., Buffalo, N. Y.), April 1975.

(3) Reno, Horace T., Chapter on Iron, Mineral Facts and Problems, 1965, Bureau of Mines Bulletin 630, Bureau of Mines, U. S. Department of the Interior, Washington, D.C., pp 455-479.

(4) Reno, Horace T., and Brantley, Francis E., Chapter on Iron, Mineral Facts and Problems, 1970, Bureau of Mines Bulletin 650, Bureau of Mines, U. S. Department of the Interior, Washington, D.C., pp 291-314.

(5) U.S. Steel Corp. (MacGannon, Harold E., Editor) The Making, Shaping, and Treating of Steel, 9th Ed., 1971, U.S. Steel Corp., Pittsburgh, PA, 1420 pp.

Crushing, Grinding, and Classifying

1. Function - The lower grade taconite and jaspilite ores from the Lake Superior District must be ground fine to free the iron oxide minerals from the associated gangue. Accordingly, these ores are crushed and ground with a classifier in the grinding circuit to remove fine clay and sands.

2. Input Materials - Mined iron ore and water.

3. Operating Parameters -

   Temperature: Ambient

   Pressure: Atmospheric

4. Utilities -

   Electrical Energy: for crushing, 0.51×10^8 joules/metric ton (14.1 kWhe/metric ton or 0.13×10^6 Btu/short ton) of ore; for grinding, 2.0×10^8 joules/metric ton (54.7 kWhe/metric ton or 0.52×10^6 Btu/short ton) of ore; for pumping, 0.19×10^8 joules/metric ton (5.3 kWhe/metric ton or 0.050×10^6 Btu/short ton) of ore

5. Waste Streams -

   Water and ore are recycled but there are some losses.

6. EPA Source Classification Code - None

7. References -

(1) Private communication with BCL staff who have visited producers.

(2) Development Document for Effluent Guidelines and Standards of Performance, Ore Mining and Dressing Industry (Draft), U. S. Environmental Protection Agency, Washington, D.C. (prepared by the Calspan Corp., Buffalo, N. Y.), April 1975.

(3) Reno, Horact T., Chapter on Iron, Mineral Facts and Problems, 1965, Bureau of Mines Bulletin 630, Bureau of Mines, U.S. Department of the Interior, Washington, D.C., pp 455-479.

(4) Reno, Horace T., and Brantley, Francis E., Chapter on Iron, Mineral Facts and Problems, 1970, Bureau of Mines Bulletin 650, Bureau of Mines, U. S. Department of the Interior, Washington, D.C., pp 291-314.

(5) U.S. Steel Corp. (MacGannon, Harold E., Editor) The Making, Shaping, and Treating of Steel, 9th Ed., 1971, U.S. Steel Corp., Pittsburgh, PA, 1420 pp.

Gravity Concentration

1. Function - Gravity concentration of iron ore involves jigging, heavy medium separation, Humphrey spirals, and hydrocyclones. Jigging is applied to coarse crushed ores, usually plus 1/4 inch. Heavy medium separators make a more rapid and precise separation on unsized ore than do jigs. Both Humphrey spirals and hydrocyclones may be operated with or without suspension medium. Humphrey spirals operate on ground ore by a combination of sluicing and centrifugal action. Hydrocyclones separate the heavier and coarser fractions of ground ore at the apex of a long cone, while lighter and finer particles overflow from the central vortex. Humphrey spirals make a better separation of fine materials than do hydrocyclones, but do not have as high capacity. Heavy-medium hydrocyclones appear to be the most favored method of gravity separation by the large producers.

2. Input Materials - Crushed or ground, classified iron ore, water, and heavy media.

3. Operating Parameters -

   Temperature: Ambient

   Pressure: Atmospheric

4. Utilities (Electrical Energy) -

   The amount of energy used depends on the type of processing. The following is typical of electrical energy usage in an iron ore concentration plant: for concentration, 0.19×10^8 joules/metric ton (5.3 kWhe/metric ton or 0.050×10^6 Btu/short ton) of ore; water handling, 0.19×10^8 joules/metric ton (5.3 kWhe/metric ton or 0.050×10^6 Btu/short ton) of ore; tailings disposal, 0.15×10^8 joules/metric ton (4.2 kWhe/metric ton or 0.040×10^6 Btu/short ton) of ore

5. Waste Materials -

   Tailings (10 to 15 percent solid loadings). In some areas, for example, Silver Bay, Minnesota, and the Groveland Mine in Dickenson County, Michigan, amphibole minerals with fibrous charactaristics are a constituent part of the tailings. These asbestic minerals release measureable quantities of asbestos fibers in the waste water.

Spills, including water.

6. EPA Source Classification Code - None

7. References -

(1) Private communication with BCL staff who have visited producers.

(2) Development Document for Effluent Guidelines and Standards of Performance, Ore Mining and Dressing Industry (Draft), U. S. Environmental Protection Agency, Washington, D.C. (prepared by Calspan Corp., Buffalo, N. Y.), April 1975.

(3) Reno, Horace T., Chapter on Iron, Mineral Facts and Problems, 1965, Bureau of Mines Bulletin 630, Bureau of Mines, U. S. Department of the Interior, Washington, D.C., pp 455-479.

(4) Reno, Horace T., and Brantley, Francis E., Chapter on Iron, Mineral Facts and Problems, 1970, Bureau of Mines Bulletin 650, Bureau of Mines, U. S. Department of the Interior, Washington, D.C., pp 291-314.

(5) U.S. Steel Corp. (MacGannon, Harold E., Editor) The Making, Shaping, and Treating of Steel, 9th Ed., 1971, U.S. Steel Corp., Pittsburgh, PA, 1420 pp.

Flotation

1. Function - In the flotation process, the surfaces of ground mineral particles, usually of the ore mineral, are selectively conditioned with reagents so that they are aerophilic in a water suspension. Thus they become selectively attached to air bubbles and rise to the surface where they float in a supernatent froth and are collected. The gangue particles are hydrophilic and remain behind. There are two types of flotation processes, the anionic--which utilizes anionic (negatively charged ion) collectors (the most common of which are fatty acids), and cationic (positively charged ion) collectors (amines). So far, only the anionic type has been used commercially for iron ore, but cationic flotation has been used to float silica and apatite away from iron minerals on an experimental scale.

2. Input Materials - Ground ore, water (densifier thickness underflow), air, and flotation reagents.

3. Operating Parameters -

   Temperature: Ambient

   Pressure: Atmospheric

4. Utilities (Electrical Energy) -

   Not known precisely, about 0.24 x 10^8 joules/metric ton (6.6 kWhe/metric ton or o.o63 x 10^6 Btu/short ton) of ore

5. Waste Streams -

   To prevent buildup of soluble salts, 20 percent of the flotation water is discharged after settling and treatment (alum).

   Solid tailings after dewatering

6. EPA Source Classification Code - None

7. References -

(1) Private communication with BCL staff who have visited producers.

(2) Development Document for Effluent Guidelines and Standards of Performance, Ore Mining and Dressing Industry (Draft), U. S. Environmental Protection Agency, Washington, D.C. (prepared by Calspan Corp., Buffalo, N. Y.), April 1975.

(3) Reno, Horace T., Chapter on Iron, Mineral Facts and Problems, 1965, Bureau of Mines Bulletin 630, Bureau of Mines, U. S. Department of the Interior, Washington, D.C., pp 455-479.

(4) Reno, Horace T., and Brantley, Francis E., Chapter on Iron, Mineral Facts and Problems, 1970, Bureau of Mines Bulletin 650, Bureau of Mines, U. S. Department of the Interior, Washington, D.C., pp 291-314.

(5) U.S. Steel Corp. (MacGannon, Harold E., Editor) The Making, Shaping, and Treating of Steel, 9th Ed., 1971, U.S. Steel Corp., Pittsburgh, PA, 1420 pp.

Magnetic Concentration

1. Function - Magnetic taconite ores are crushed and ground to free the magnetite mineral and are usually concentrated in low intensity wet magnetic separators. The concentration may be performed in three stages in "rough", "intermediate", and "finish" magnetic separators. Concentrate from the rough or "cobber" separation is reground and magnetically separated in a second, cleaner magnetic separator; the concentrates from this second step are then sized in closed circuit in a hydrocyclone; oversize is recycled and undersize is concentrated further (mechanically) in a hydroseparator; concentrates from the hydroseparator are given a final treatment in a "finish" magnetic separator.

   Dry magnetic separation systems are not as widely applied as wet systems. There are two types: low-intensity and high-intensity magnetic separators. There is also a wet high-intensity separator, but it has not been used commercially.

2. Input Materials - Ground ore

3. Operating Parameters -

   Temperature: Ambient

   Pressure: Atmospheric

4. Utilities -

   Electrical energy for magnetic separation: about 0.040×10^8 joules/metric ton (1.1 kWhe/metric ton or 0.011×10^6 Btu/short ton) of ore

5. Waste Streams -

   Slurries of tailings to tailings basin from three magnetic separations, and from the intermediate hydroseparation process

6. EPA Source Classification Code - None

7. References -

(1) Private communication with BCL staff who have visited producers.

(2) Development Document for Effluent Guidelines and Standards of Performance, Ore Mining and Dressing Industry (Draft), U. S. Environmental Protection Agency, Washington, D.C. (prepared by Calspan Corp., Buffalo, N. Y.), April 1975.

(3) Reno, Horace T., Chapter on Iron, Mineral Facts and Problems, 1965, Bureau of Mines Bulletin 630, Bureau of Mines, U. S. Department of the Interior, Washington, D.C., pp 455-479.

(4) Reno, Horace T., and Brantley, Francis E., Chapter on Iron, Mineral Facts and Problems, 1970, Bureau of Mines Bulletin 650, Bureau of Mines, U. S. Department of the Interior, Washington, D.C., pp 291-314.

(5) U.S. Steel Corp. (MacGannon, Harold E., Editor) The Making, Shaping, and Treating of Steel, 9th Ed., 1971, U.S. Steel Corp., Pittsburgh, PA, 1420 pp.

Pelletizing

1. Function - All minus 0.64 cm (1/4 inch) iron ores are agglomerated before reduction in the blast furnace. Pelletizing involves the formation of pellets or balls from finely ground iron ore. In a typical operation with finely ground magnetic taconite ores, the concentrate from the finisher magnetic separation passes through a thickener and is filtered. The filter cake is mixed with small amounts of bentonite and measured amounts of water in a balling drum. The "green" pellets from the balling drum are first dried, then bonded by heating in an agglomeration furnace. There is also a traveling grate system which is used for producing pellets.

2. Input Materials - Finely ground iron ore, water, and, usually, bentonite [approximately 8 kg/metric ton (16 lb/ton) of pellets]

3. Operating Parameters -

   Temperature: (1204-1371 C) (2200-2500 F)

   Pressure: Atmospheric

4. Utilities -

   Electrical Energy: 0.19 x 10^8 joules/metric ton (5.4 kWhe/metric ton or 0.051 x 10^6 Btu/short ton) of pellets
   Natural Gas: 8580 cu meters/metric ton (275,000 cu ft/short ton) of pellets
   Fuel Oil: 6.2 liters/metric ton (1.5 gal/short ton) of pellets

5. Waste Streams -

   Exhaust gases from the agglomeration furnace

   Fine particles of minerals in thickener overflow (particularly in cases where the thickener overflow is not recirculated)

   Spills

6. EPA Source Classification Code - None

7. References -

(1) Private communication with BCL staff who have visited producers.

(2) Development Document for Effluent Guidelines and Standards of Performance, Ore Mining and Dressing Industry (Draft), U. S. Environmental Protection Agency, Washington, D.C. (prepared by Calspan Corp., Buffalo, N. Y.), April 1975.

(3) Reno, Horace T., Chapter on Iron, Mineral Facts and Problems, 1965, Bureau of Mines Bulletin 630, Bureau of Mines, U. S. Department of the Interior, Washington, D.C., pp 455-479.

(4) Reno, Horace T., and Brantley, Francis E., Chapter on Iron, Mineral Facts and Problems, 1970, Bureau of Mines Bulletin 650, Bureau of Mines, U. S. Department of the Interior, Washington, D.C., pp 291-314.

(5) U.S. Steel Corp. (MacGannon, Harold E., Editor) The Making, Shaping, and Treating of Steel, 9th Ed., 1971, U.S. Steel Corp., Pittsburgh, PA, 1420 pp.

Sintering

1. Function - Sintering does not require as uniform a ground input material as does pelletizing. It usually involves the mixing of small amounts of coke and limestone with reclaimed steel plant iron ore dusts (to make them self-fluxing). This is followed by combustion to form a granular coarse self-fluxing product for the blast furnace charge. Combustion of the mixture takes place on a traveling grate provided with a downdraft to promote combustion. After discharge from the end of the traveling grate, the sinter is crushed, cooled, and screened. Undersize is resintered.

2. Input Materials - Iron ore fines, blast furnace dust, sludge containing metallics, mill scale, melt shop slag, blast furnace oxygen dust, limestone or dolomite fines, and coke fines

3. Operating Parameters -

   Temperature: 1st Section, 1149 C (2100 F); Exit 816 C (1500 F)

   Pressure: Atmospheric

4. Utilities -

   Fuel requirements not known precisely. U.S. Steel Corp. operators report that the fuel requirement per ton of ore for sintering is about double that of pelletizing.

5. Waste Streams -

   Air Emissions

   Iron ore dust consisting of Fe_2O_3 and Fe_3O_4 with some silica and limestone

   Limestone dust, principally calcite

   Coke dust

   Combustion gases from ignition of coke oven gas and natural gas fuels (with some use of fuel oil)

Sinter dust--iron oxides, calcite iron-calcium silicate and quartz

The major problem in the control of emissions from a sinter reclamation plant is minimizing emissions from the wind box of the sintering machines. There are 45 sinter reclamation plants in the U.S. operating 72 sintering strands, 93 percent of which are controlled with electrostatic precipitors, cyclones, or scrubbers.

The chemical composition of particulate emissions from three plants having dust collecting systems are shown in the following table:

Particulate Component	Plant F Weight Percent	Plant G Weight Percent	Plant H Weight Percent
Fe_2O_3	33.9	11.7	28.0
CaO	7.1	10.9	15.0
MgO	5.3	0.4	2.0
K_2O	5.2	0.6	8.1
SiO_2	4.8	2.4	4.6
Al_2O_3	2.6	4.3	2.5
Na_2O	1.6	0.8	0.0
ZnO	0.4	0.1	0.0
MnO	0.2	0.1	0.0
Chlorides	8.5	3.0	8.8
Sulfates	7.5	16.5	2.1
Hydrocarbons	7.4	36.9	0.0
Other	1.6	0.0	0.0
Loss on Ignition	13.9	12.3	28.9
Total	100.0	100.0	100.0

Typical size distribution of particulates from the wind box exhausts on two sintering strands [each with a flow rate of 10,993 m^3/min (385000 acfm) at 118 C (245 F)] controlled by a multicyclone followed by an electrostatic precipitator is as follows:

Particulate Size, microns	Cumulative Weight Percent Retained Test No. 1	Cumulative Weight Percent Retained Test No. 2
>12.00	54.36	10.43
7.50	61.56	21.50
5.10	65.05	30.97
3.50	66.62	40.20
2.20	69.22	47.89
1.10	70.49	58.65
0.68	72.50	66.99
0.46	73.56	76.48
<0.46	100.00	100.00

Note: Particle size determinations were made with an Andersen Cascade Impactor.

The gaseous emissions obtained from this same test are as follows:

Gaseous Component	Milligrams/Nm^3	Grains/SCFD*	ppm
Condensable hydrocarbons	1.036	0.00453	-
Noncondensable hydrocarbons	812.11	0.3539	230
Fluoride	3.21	0.00140	-
Carbon monoxide	-	-	8000
Sulfur dioxide	-	-	900
Sulfur trioxide	-	-	11.5
Nitrogen oxides	-	-	71.4

*Standard cubic foot (dry).

The particulate contents at the inlet and outlet sides of the electrostatic precipitators at this plant during this test were as follows:

	mg/m^3 (dry)	grains/ft^3 (dry)
Average ESP inlet	595	0.26
Average ESP outlet	69	0.03

This represents a collection efficiency of 88.4 percent. The corresponding release of emissions to the atomosphere amounted to 0.214 kg/metric ton (0.428 lb/short ton) of sinter.

6. EPA Source Classification Code - None

7. References -

(1) Private communication with BCL staff who have visited producers.

(2) Development Document for Effluent Guidelines and Standards of Performance, Ore Mining and Dressing Industry (Draft), U.S. Environmental Protection Agency, Washington, D.C. (prepared by Calspan Corp., Buffalo, N.Y.), April 1975.

(3) Reno, Horace T., Chapter on Iron, Mineral Facts and Problems, 1965, Bureau of Mines Bulletin 630, Bureau of Mines, U.S. Department of the Interior, Washington, D.C., pp 455-479.

(4) Reno, Horace T., and Brantley, Francis E., Chapter on Iron, Mineral Facts and Problems, 1970, Bureau of Mines Bulletin 650, Bureau of Mines, U.S. Department of the Interior, Washington, D.C., pp 219-314.

(5) U.S. Steel Corp. (MacGannon, Harold E., Editor) The Making, Shaping, and Treating of Steel, 9th Ed., 1971, U.S. Steel Corp., Pittsburgh, PA, 1420 pp.

(6) Control of Reclamation (Sinter) Plant Emissions Using Electrostatic Precipitators, EPA-600/2-76-002, U.S. Environmental Protection Agency, Washington, D.C. (prepared by John Varga, Jr., Battelle Columbus Laboratories, Columbus, Ohio) January 1976.

Briquetting

1. Function - Briquetting is a process by which iron ore fines are mixed with a binder such as molasses and lime and formed into briquettes in either mold presses or roll presses. In a related process, hot briquetting, no binder is required; the ore is heated, fed into a pressure-roll machine to produce the briquettes. Neither process has been used commercially, but cold briquetting is coming on stream on a very small scale for agglomerating waste oxides (mill scale, blast furnace dust, B.O.F. dust, etc.).

2. Input Materials - Ore fines, waste oxides, mill scale, dusts from smelting operations

3. Operating Parameters

   Temperature: Briquetting, Ambient;
   Hot Briquetting, 871-1038 C (1600-1900 F)

   Pressure: In hot briquetting, roll separating loads range from 68 to 270 metric ton (75 to 300 short tons) for roll diameters of 51 to 71 centimeters (20-28 inches) and roll widths of 12 to 25 centimeters (4.7-10 inches).

4. Utilities -

   Energy usage, not known precisely. U.S. Steel Corp. operators report that hot briquetting requires about the same amount of fuel per ton of ore as pelletizing.

5. Waste Streams -

   Dust, particulates, particularly from hot briquetting

   Dust, fumes from the pressure roll machine discharge

6. EPA Source Classification Code - None

7. References -

   (1) Private communication with BCL staff who have visited producers.

(2) Development Document for Effluent Guidelines and Standards of Performance, Ore Mining and Dressing Industry (Draft), U. S. Environmental Protection Agency, Washington, D.C. (prepared by Calspan Corp., Buffalo, N. Y.), April 1975.

(3) Reno, Horace T., Chapter on Iron, Mineral Facts and Problems, 1965, Bureau of Mines Bulletin 630, Bureau of Mines, U. S. Department of the Interior, Washington, D.C., pp 455-479.

(4) Reno, Horace T., and Brantley, Francis E., Chapter on Iron, Mineral Facts and Problems, 1970, Bureau of Mines Bulletin 650, Bureau of Mines, U. S. Department of the Interior, Washington, D.C., pp 219-314.

(5) U.S. Steel Corp. (MacGannon, Harold E., Editor) The Making, Shaping, and Treating of Steel, 9th Ed., 1971, U.S. Steel Corp., Pittsburgh, PA, 1420 pp.

Nodulizing

1. Function - Nodulizing is another method of agglomerating iron ore fines. Ore fines are heated in a rotary kiln to incipient fusion, and are formed into balls by the rotary motion of the kiln. It is not used to any great extent because the nodulized product is not acceptable as blast furnace burden because it is non-uniform in size and has inferior reducibility. Moreover, it has the disadvantage of high heat consumption. Nodules are acceptable for open hearth use.

2. Input Materials - Ground iron ore

3. Operating Parameters -

Temperature: 1260-1371 C (2300-2500 F)

Pressure: Atmospheric

4. Utilities -

Natural gas (or equivalent): 62.4-125 cu meters/metric ton (2000-4000 cu ft/short ton) of nodules

5. Waste Streams -

Exhaust gases from kiln

Dust, particulates in exhaust gases, and accompanying kiln discharge

6. EPA Source Classification Code - None

7. References -

(1) Private communication with BCL staff who have visited producers.

(2) Development Document for Effluent Guidelines and Standards of Performance, Ore Mining and Dressing Industry (Draft), U. S. Environmental Protection Agency, Washington, D.C. (prepared by Calspan Corp., Buffalo, N. Y.), April 1975.

(3) Reno, Horace T., Chapter on Iron, Mineral Facts and Problems, 1965, Bureau of Mines Bulletin 630, Bureau of Mines, U. S. Department of the Interior, Washington, D.C., pp 455-479.

(4) Reno, Horace T., and Brantley, Francis E., Chapter on Iron, Mineral Facts and Problems, 1970, Bureau of Mines Bulletin 650, Bureau of Mines, U. S. Department of the Interior, Washington, D.C., pp 291-314.

(5) U.S. Steel Corp. (MacGannon, Harold E., Editor) The Making, Shaping, and Treating of Steel, 9th Ed., 1971, U.S. Steel Corp., Pittsburgh, PA, 1420 pp.

Lead and Zinc

Lead and zinc minerals occur in many major ore bodies in such intimate mixtures that they must be mined together. At some stage of processing, separations must be made. In addition, lead and zinc ores commonly contain other metals, such as copper, bismuth, antimony, gold, and silver, which for technological or economical reasons must be separated from lead and zinc. The processes for treating lead ores, zinc ores, and lead-zinc ores are highly complicated operations interwoven with each other as well as with processes for copper, precious metals, cadmium, etc.

The total number of mine sources of zinc and lead in the United States has been placed at about 300.

The United States is not self-sufficient in lead production from domestic ores. Currently about 26 percent of consumption is imported. Lead from primary production is only about half of our consumption. Currently, our zinc production from primary sources is only about one-third of domestic consumption.

For purposes of this report, the raw materials for the production of lead and zinc are classified as follows:

(a) Lead ores
(b) Zinc ores
(c) Lead-zinc ores
(d) Copper-lead-zinc ores
(e) Complex ores containing lead and/or zinc values.

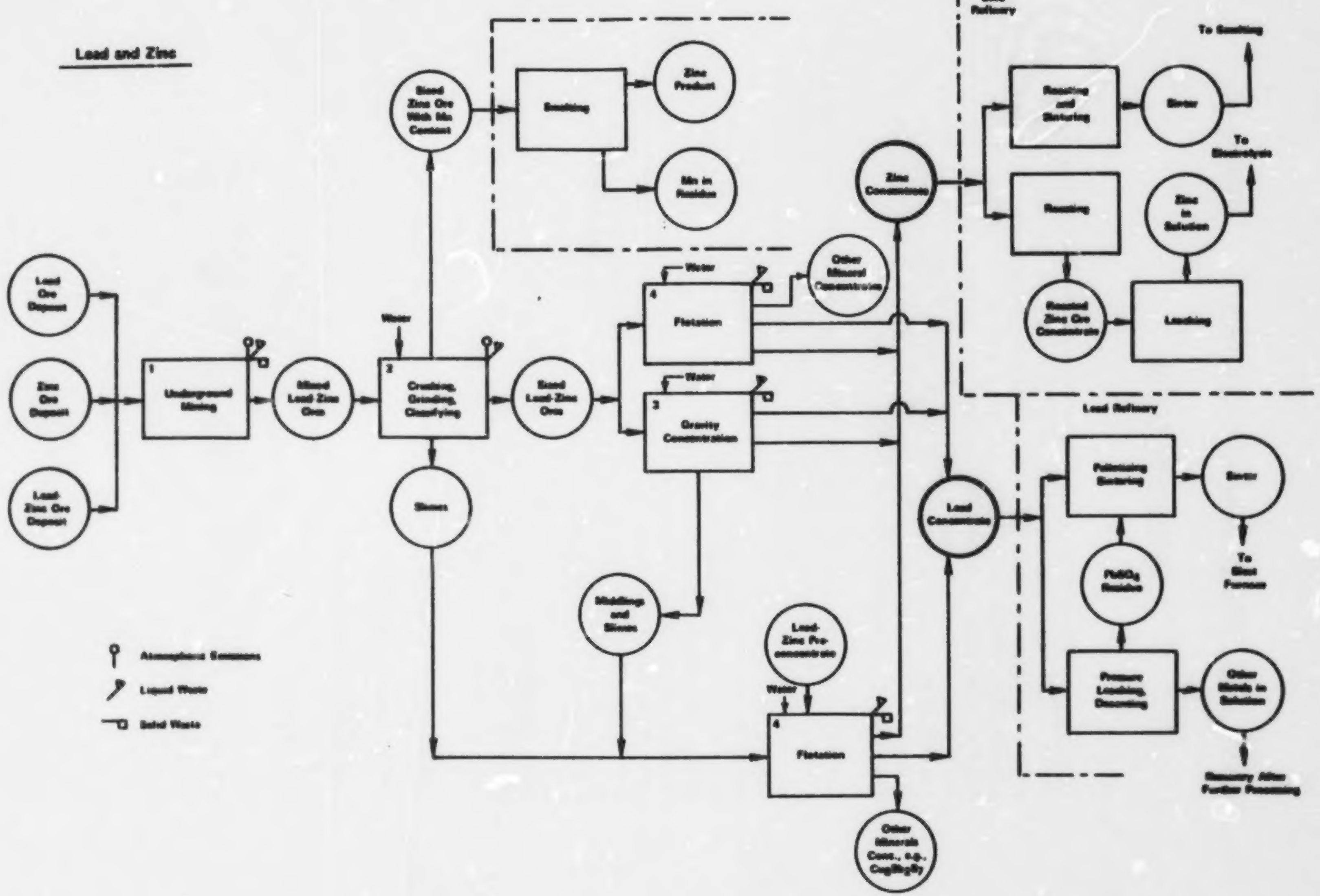
The lead-zinc segment of the mining industry produces concentrates of the ores being worked by processes to be described. The products of the industry are:

(a) Lead concentrates
(b) Zinc concentrates, and
(c) Other metal concentrates depending on the minerology of the ore body.

Almost all lead and zinc ores are mined by underground techniques in contrast to the major open-pit operations of the copper industry. Limited mining of lead and zinc by small open-pit operations has been used in the Tri-state region of Missouri and in Washington. Some zinc mines in the early stages of their development are also mined by open-pit methods. Underground methods most commonly used for lead and zinc mining include block-caving, cut and fill, room and pillar, and various stoping techniques.

Ores of lead and zinc are concentrated using two general methods, gravity and flotation. In gravity concentration, advantage is taken of the high specific gravity of the lead minerals galena (specific gravity 7) and of the zinc mineral sphalerite (specific gravity 4.7) to separate them from the lighter gangue or nonore materials. Gravity separation is usually done by float-sink methods in so-called heavy media. The flotation process with lead and zinc ores is quite complex and exhibits many variations depending on the type of ore, the association of minerals within the ore, and the desired grade and recovery levels of lead or zinc concentrate required. By the use of relatively small quantities of conditioning chemicals, it is possible to manipulate the surface properties of the different sulfide materials so that high-grade concentrates of lead and zinc can be produced from even the most complex ores of lead, zinc, copper, etc.

Lead and Zinc


Lead Ore Deposit
Zinc Ore Deposit
Lead-Zinc Ore Deposit
1 Underground Mining
Mixed Lead-Zinc Ore
Water
2 Crushing, Grinding, Classifying
Sized Zinc Ore With Mn Content
Smelting
Zinc Product
Mn in Residue
Slimes
Sized Lead-Zinc Ore
Water
4 Flotation
Other Mineral Concentrates
Water
3 Gravity Concentration
Middlings and Slimes
Lead-Zinc Pre-concentrate
Water
4 Flotation
Other Minerals Conc., e.g., Cu, Ag, Sb
Zinc Concentrate
Lead Concentrate
Zinc Refinery
Roasting and Sintering
Sinter
To Smelting
Roasting
Zinc in Solution
To Electrolysis
Roasted Zinc Ore Concentrate
Leaching
Lead Refinery
Pelletizing Sintering
Sinter
To Blast Furnace
$PbSO_4$ Residue
Pressure Leaching, Decanting
Other Metals in Solution
Recovery After Further Processing
Atmospheric Emissions
Liquid Waste
Solid Waste

LEAD AND ZINC - ALL TYPES OF MIXED LEAD-ZINC ORES PROCESS NO. 1

Underground Mining

1. **Function** - Lead and zinc ores are largely produced from underground mines. The most common lead mineral mined is galena, lead sulfide, which is often associated with the most common zinc sulfide mineral, sphalerite, and with copper, silver, and gold. Other common zinc minerals besides sphalerite include the oxide zincite, the silicate zinc willemite, and a complex iron-zinc-manganese mineral, franklinite. Sphalerite is often found in association with sulfides of lead and iron. Copper, gold, silver, and cadmium are also found in association with sphalerite.

   The largest producer of lead is the "New Lead Belt" of Southeast Missouri. Ore bodies there which contain some zinc and copper sulfides are large, horizontally-lying deposits which lend themselves to the room and pillar method of mining. Zinc and lead-zinc deposits of the Tri-State, Upper Missippi Valley, Tennessee, Virginia, and the Metaline (Washington) districts also tend to be large, horizontal ore bodies, and open stopes with pillars (breast stopes) are used exclusively in mining these ores. Zinc and lead-zinc deposits in the western states do not have a self-supporting overlying rock structure; accordingly, they are mined by artificially supported stoping methods which include shrinkage stoping, cut and fill stoping, and timbered stoping.

2. **Input Materials** - Explosives: 0.45 kg/metric ton (0.9 lb/short ton) of lead and zinc ore; Fuel oil: 1.67 liters/metric ton (0.4 gal/short ton) of lead and zinc ore

3. **Operating Parameters** -

   Temperature: Ambient

   Pressure: Atmospheric

4. **Utilities** -

   Electrical energy: 1.8×10^8 joules/metric ton (51 kWhe/metric ton or 0.48×10^6 Btu/short ton) of lead and zinc ore

5. Waste Streams -

Raw mine drainage containing suspended solids from blasting, oils and greases. Because of the associated limestone or dolomite, the water may be excessively alkaline.

Waste rock from shafts, cross-cuts, etc.

6. EPA Source Classification Code - None

7. References -

(1) Census of Mineral Industries (1967), U. S. Department of Commerce, Major Group 10, Table 3A, p. 10B-11, and Table 7, p. 10B-23.

(2) Private communication with BCL staff who have visited producers.

(3) Rausch, Donald O., and Mariacher, Burt C., Editors, AIME World Symposium on the Mining and Metallurgy of Lead and Zinc, 1970, Vol 1, Mining and Concentrating of Lead and Zinc, 1017 pp.

(4) Paone, James, Chapter on Lead, Mineral Facts and Problems, 1970, Bureau of Mines Bulletin 650, Bureau of Mines, U. S. Department of the Interior, Washington, D.C., pp 603-620.

(5) Heindl, R. A., Chapter on Zinc, Ibid., Ref. (4), pp 805-824.

(6) Development Document for Effluent Guidelines and Standards of Performance, Ore Mining and Dressing Industry (Draft), U. S. Environmental Protection Agency, Washington, D.C. (prepared by Calspan Corp., Buffalo, N. Y.), April 1975.

LEAD AND ZINC - ALL TYPES OF MIXED LEAD-ZINC ORES PROCESS NO. 2

Crushing, Grinding, and Classifying

1. Function - simple ores such as coarsely disseminated lead, lead-zinc, or zinc minerals occurring in low specific gravity gangue (a type typical in the Mississippi Valley and the Eastern United States) are crushed and ground in closed circuit with screens or classifiers to provide a sized feed to gravity concentrators. Fines and middlings from the classifiers (or screens) are concentrated by flotation (Process 4). The more complex sulfide ores of the Western United States require fine grinding in a closed circuit with a classifier to free the mixtures of disseminated minerals from the gangue, following which the ore is selectively concentrated by flotation (Process 4) to yield lead, zinc, copper, and copper-pyrite concentrates. Regrinding with a classifier in a closed circuit is frequently necessary as an interim step in the flotation treatment (Process 4).

2. Input Materials - Mined ore and water.

3. Operating Parameters -

   Temperature: Ambient (mill temperature)

   Pressure: Atmospheric

4. Utilities -

   Electrical energy: for crushing, 0.083×10^8 joules/metric ton (2.3 kWhe/metric ton or 0.022×10^6 Btu/short ton) of ore; for grinding, 0.070×10^8 joules/metric ton (19 kWhe/metric ton or 0.18×10^6 Btu/short ton) of ore

5. Waste Streams -

   Dust, particulates in crushing

   Spills in grinding circuits

   Ground ore and ore slurries pass on to subsequent concentration steps.

6. EPA Source Classification Code - None

7. References -

(1) Census of Mineral Industries (1967), U. S. Department of Commerce, Major Group 10, Table 3A, p. 10B-11, and Table 7, p. 10B-23.

(2) Private communication with BCL staff who have visited producers.

(3) Rausch, Donald O., and Mariacher, Burt C., Editors, AIME World Symposium on the Mining and Metallurgy of Lead and Zinc, 1970, Vol 1, Mining and Concentrating of Lead and Zinc, 1017 pp.

(4) Paone, James, Chapter on Lead, Mineral Facts and Problems, 1970, Bureau of Mines Bulletin 650, Bureau of Mines, U. S. Department of the Interior, Washington, D.C., pp 603-620.

(5) Heindl, R. A., Chapter on Zinc, Ibid., Ref. (4), pp 805-824.

(6) Development Document for Effluent Guidelines and Standards of Performance, Ore Mining and Dressing Industry (Draft), U. S. Environmental Protection Agency, Washington, D.C. (prepared by Calspan Corp., Buffalo, N. Y.), April 1975.

LEAD AND ZINC - ALL TYPES OF MIXED LEAD-ZINC ORES PROCESS NO. 3

Gravity Concentration

1. Function - Lead and zinc ores mined in the Mississippi Valley and the Eastern United States typically contain coarsely disseminated lead and lead-zinc ores associated with a low specific gravity gangue. In a number of cases, practice is to save expensive grinding costs with a preliminary gravity separation. Only the concentrates from the gravity separator need to be finely ground for further concentration by flotation methods. In preparation for the preliminary gravity concentration, the ore, after primary crushing, is fed to a secondary crusher operating in closed circuit with screens or classifiers to produce about a minus 4.4 cm (1-3/4 inch), plus 0.64 cm (1/4 inch) feed size. Separated fines and middlings are sent directly to the flotation grinding section. The sized feed (oversize from the screens) then goes to the gravity concentrators which may be either jigs or heavy-media cone separators. Media used in the cone separators may be either ferrosilicon, magnetite, ferrosilicon-magnetite mixtures, or fine galena. Tailings from the gravity concentrators are discarded.

   Alternatively, the concentrates from gravity separation may go directly to the smelter. Coarse lead concentrates can go directly to the sintering plant.

2. Input Materials - Sized ore from the secondary crushing-screening operation and water.

3. Operating Parameters -

   Temperature: Ambient (mill temperature)

   Pressure: Atmospheric

4. Utilities -

   Electrical energy: for heavy-media separation, 0.020×10^8 joules/metric ton (0.55 kWhe/metric ton or 0.005×10^6 Btu/short ton) of ore

   Consumption of ferrosilicon is about 0.35 kg/metric ton (0.7 lb/short ton) of feed.

5. Waste Streams -

Float product from heavy-media separation or tailings discard from jigs containing 25-50 percent solids, to tailing pond

6. EPA Source Classification Code - None

7. References -

(1) Census of Mineral Industries (1967), U. S. Department of Commerce, Major Group 10, Table 3A, p. 10B-11, and Table 7, p. 10B-23.

(2) Private communication with BCL staff who have visited producers.

(3) Rausch, Donald O., and Mariacher, Burt C., Editors, AIME World Symposium on the Mining and Metallurgy of Lead and Zinc, 1970, Vol 1, Mining and Concentrating of Lead and Zinc, 1017 pp.

(4) Paone, James, Chapter on Lead, Mineral Facts and Problems, 1970, Bureau of Mines Bulletin 650, Bureau of Mines, U. S. Department of the Interior, Washington, D.C., pp 603-620.

(5) Heindl, R. A., Chapter on Zinc, Ibid., Ref. (4), pp 805-824.

(6) Development Document for Effluent Guidelines and Standards of Performance, Ore Mining and Dressing Industry (Draft), U. S. Environmental Protection Agency, Washington, D.C. (prepared by Calspan Corp., Buffalo, N. Y.), April 1975.

LEAD AND ZINC - ALL TYPES OF MIXED LEAD-ZINC ORES   PROCESS NO. 4

Flotation

1. Function - Generally in U. S. practice with lead-zinc ores, the procedure is to crush and grind the ore in closed circuit with a classifier to a size where the disseminated ore minerals are freed from the gangue and each other in the case of complex ores. This is followed by a separation of the desired mineral particles by a selective flotation process. The flotation process entails adding chemical reagents to finely ground ore minerals suspended in water with air bubbles. This treatment of the surfaces of the particles makes some particles aerophyllic and some hydrophillic so that the desired mineral particles may be separated out of the water suspension by attachment to the air bubbles. These float up to a froth on the surface and are scraped off. Where several ore minerals are separated, sequential differential flotation methods are used. Reagents termed depressants are used to change the surface characteristics of some of the desired mineral particles so that they will not float while another is being floated. Thus, three or more successive flotation circuits are used to produce individual concentrates of copper, lead, and zinc from an ore containing these three metals. Ordinarily, each of the three circuits are similar in that each first makes a "rougher" concentrate that is subsequently "cleaned" and "recleaned".

2. Input Materials - Ground ore, water, and flotation reagents such as sodium ethyl xanthate as a collector, sodium sulfite as a zinc depressor in lead flotation, cresylic acid as a frother, lime for pH control, zinc sulfate conditioner in the lead flotation circuit, and copper sulfite conditioner in the lead flotation circuit.

3. Operating Parameters -

   Temperature: Ambient (mill temperature)

   Pressure: Atmospheric

4. Utilities -

   Electrical energy: for conditioning, flotation, pumping, miscellaneous - 0.27×10^8 joules/metric ton (7.4 kWhe/metric ton or 0.07×10^6 Btu/short ton) of ore

5. Waste Streams -

A large volume of tailings or gangue material remains as the underflow from the last cell in the flotation circuit. They are typically adjusted to a slurry which can be hydraulically transported to a tailings pond. Generally, lead, zinc, and copper sulfide flotation suspensions are run at a pH of 8.5-11.0 which is maintained by hydrated lime additions.

The waste stream contains dissolved solids and flotation reagents.

Accidental spills of reagents are a potential source of adverse discharge.

6. EPA Source Classification Code - None

7. References -

(1) Census of Mineral Industries (1967), U. S. Department of Commerce, Major Group 10, Table 3A, p. 10B-11, and Table 7, p. 10B-23.

(2) Private communication with BCL staff who have visited producers.

(3) Rausch, Donald O., and Mariacher, Burt C., Editors, AIME World Symposium on the Mining and Metallurgy of Lead and Zinc, 1970, Vol 1, Mining and Concentrating of Lead and Zinc, 1017 pp.

(4) Paone, James, Chapter on Lead, Mineral Facts and Problems, 1970, Bureau of Mines Bulletin 650, Bureau of Mines, U. S. Department of the Interior, Washington, D.C., pp 603-620.

(5) Heindl, R. A., Chapter on Zinc, Ibid., Ref. (4), pp 805-824.

(6) Development Document for Effluent Guidelines and Standards of Performance, Ore Mining and Dressing Industry (Draft), U. S. Environmental Protection Agency, Washington, D.C. (prepared by Calspan Corp., Buffalo, N. Y.), April 1975.

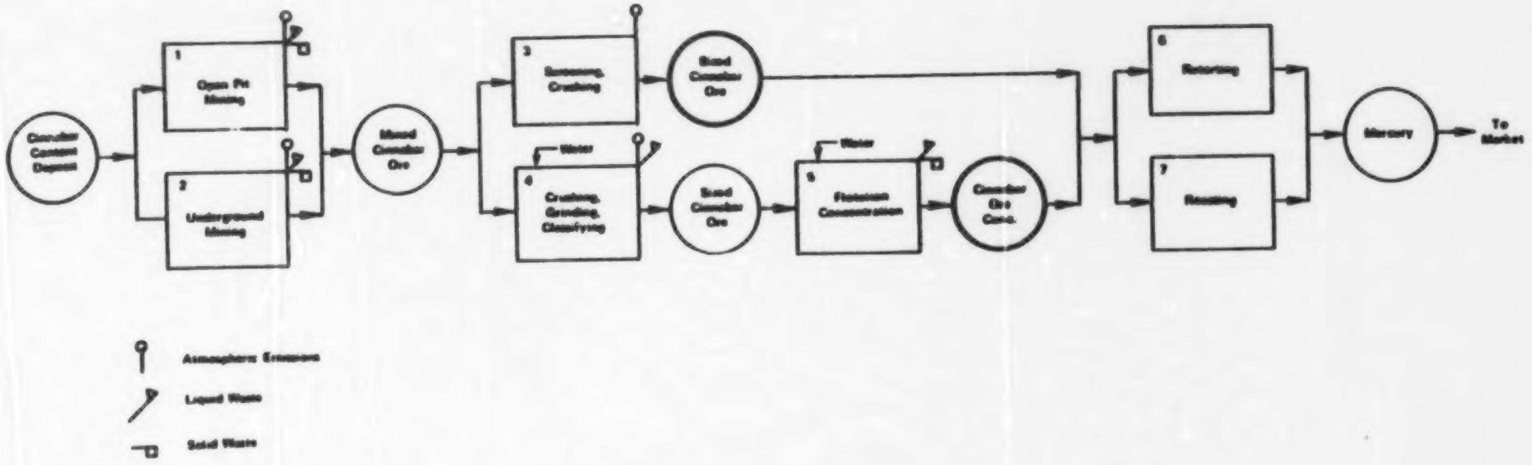
Mercury

The mercury mining industry has shown very variable character in recent years. Domestic production from mines was about 28,000 flasks in 1970 (a flask is equal to 76 pounds of mercury), almost 18,000 flasks in 1971, and only 7,286 flasks in 1972, the latest year for which production figures are available. A total of 71 mines reported production of mercury in 1971, but only 21 made claims in 1972. In 1975, a single, large, new operation started production using flotation concentration in the process. This operation represents a doubling of domestic production capacity.

Mercury occurs in almost all natural substances in the parts per billion to parts per million range, but in order for a "deposit" to be minable, a mercury ore must have at least 4 or 5 pounds of mercury to a ton of ore (2000-2500 parts per million) which is many times greater than in most rocks. The mineral in most mercury ores is cinnabar, HgS.

The product of the mercury mining and beneficiating segment of the industry is a cinnabar concentrate or mercury metal depending on whether or not the mining company has the pyrometallurgical equipment necessary to win the metal from the ore in a simple furnacing operation. Ore concentrates may be heated in retorts, multiple-hearth roasters, or rotary kilns which can be located at the mine and mill site or elsewhere. If the furnacing equipment is available, mercury metal is shipped from the mine.

Mercury


Cinnabar Content Deposit
1
Open Pit Mining
2
Underground Mining
Mined Cinnabar Ore
3
Screening, Crushing
Water
4
Crushing, Grinding, Classifying
Sized Cinnabar Ore
Sized Cinnabar Ore
Water
5
Flotation Concentration
Cinnabar Ore Conc.
6
Retorting
7
Roasting
Mercury
To Market
Atmospheric Emissions
Liquid Waste
Solid Waste

MERCURY - CINNABAR DEPOSITS PROCESS NO. 1

Open Pit Mining

1. Function - Open pit surface mining is accomplished by the normal drilling, blasting, digging, and loading operations. Open pit methods have accounted for about one-third of U. S. mercury production in recent years. However, owing to slackened demand, many open pit mercury mines have shut down. Only two of the lower cost open pit mines remain active. The mineral mined is cinnabar, HgS; ores from open pit mines contain upwards of 2.5 kg of mercury per metric ton (5 lbs/short ton).

2. Input Materials - Explosives: amount not known precisely, about 1.75 kg/metric ton (3.5 lb/short ton) of ore

3. Operating Parameters -

   Temperature: Ambient

   Pressure: Atmospheric

4. Utilities -

   Electrical energy: about 1.55×10^8 joules/metric ton (43 kWhe/metric ton or 0.41×10^6 Btu/short ton) of ore.

   Diesel fuel (or equivalent): about 2.8 liters/metric ton (0.67 gal/short ton) of ore

5. Waste Streams -

   Emissions of mercury vapor from open deposits of cinnabar ore through natural heat. The emission factor from mining has been reported as 0.005 kg/metric ton (0.01 lb/short ton) of ore.

   Runoff and ground water seepage caused by precipitation. Negligible in the arid regions where open pit mines are currently in operation.

   Overburden and gangue minerals. Silica and carbonate minerals predominantly. Some deposits contain pyrite, FeS_2, and marcasite, FeS_2. Stibnite, Sb_2S_3, and orpiment, As_2S_3, occur rarely.

6. EPA Source Classification Code - None

7. References -

(1) Private communication with members of the BCL staff who have conferred with producers.

(2) Pennington, J. W., "Mercury--A Material Survey", U. S. Bureau of Mines Circular 7941 (1959), Department of the Interior, Washington, D.C.

(3) Shelton, John E., Chapter on Mercury, Mineral Facts and Problems, 1965, U. S. Bureau of Mines Bulletin 630, Department of the Interior, Washington, D.C., pp 573-581.

(4) Greenspoon, Gertrude N., Chapter on Mercury, Mineral Facts and Problems, 1970, U. S. Bureau of Mines Bulletin 650, Department of the Interior, Washington, D.C., pp 639-652.

(5) Development Document for Effluent Guidelines and Standards of Performance, Ore Mining and Dressing Industry (Draft), U. S. Environmental Protection Agency, Washington, D.C. (prepared by Calspan Corp., Buffalo, N. Y.), April 1975.

(6) Anderson, D.,"Emission Factors for Trace Substance," Report PB 230894, Springfield, Va., Nat. Tech. Information Service (Dec. 1973).

MERCURY - CINNABAR DEPOSITS PROCESS NO. 2

Underground Mining

1. Function - Over the past few years, about two-thirds of the mercury produced came from underground mines. The larger mines are mined by square set stoping. Shrinkage and sublevel stoping methods are also used. Ore is broken by blasting and removed by scrapers or mechanical loaders.

2. Input Materials - Explosives: 0.41 kg/metric ton (0.82 lb/short ton) of ore

3. Operating Parameters -

   Temperature: Ambient

   Pressure: Atmospheric

4. Utilities -

   Electrical energy: 2.3×10^8 joules/metric ton (64 kWhe/metric ton or 0.61×10^6 Btu/short ton) of ore

5. Waste Streams -

   Ground water seepage

   Water emissions from milling tailings used to backfill stopes where such backfilling is practical

   Waste rock from shafts, cross-cuts, etc.

6. EPA Source Classification Code - None

7. References -

   (1) Private communication with members of the BCL staff who have conferred with producers.

   (2) Pennington, J. W., "Mercury--A Material Survey", U. S. Bureau of Mines Circular 7941 (1959), Department of the Interior, Washington, D.C.

(3) Shelton, John E., Chapter on Mercury, Mineral Facts and Problems, 1965, U. S. Bureau of Mines Bulletin 630, Department of the Interior, Washington, D.C., pp 573-581.

(4) Greenspoon, Gertrude N., Chapter on Mercury, Mineral Facts and Problems, 1970, U. S. Bureau of Mines Bulletin 650, Department of the Interior, Washington, D.C., pp 639-652.

(5) Development Document for Effluent Guidelines and Standards of Performance, Ore Mining and Dressing Industry (Draft), U. S. Environmental Protection Agency, Washington, D.C. (prepared by Calspan Corp., Buffalo, N. Y.), April 1975.

MERCURY - CINNABAR DEPOSITS　　　　PROCESS NO. 3

Crushing and Screening

1. **Function** - Crushing and screening at mines operating on fairly high grade ores is done to prepare a sized feed for the retort or furnace. With lower grade ores, the crushing and screening operations also afford a means of partial separation. In most types of ore, cinnabar breaks more readily and into smaller particles than does the associated gangue, so that a rough separation can be achieved by screening and discarding the oversize waste minerals.

2. **Input Materials** - Mined ore

3. **Operating Parameters** -

   Temperature: Ambient

   Pressure: Atmospheric

4. **Utilities** -

   Electrical energy: 0.74×10^8 joules/metric ton (20.5 kWhe/metric ton or 0.20×10^6 Btu/short ton) of ore

5. **Waste Streams** -

   Dust, particulates in crushing and screening operation

   Oversize waste minerals to stock pile

6. **EPA Source Classification Code** - None

7. **References** -

   (1) Private communication with members of the BCL staff who have conferred with producers.

   (2) Pennington, J. W., "Mercury--A Material Survey", U. S. Bureau of Mines Circular 7941 (1959), Department of the Interior, Washington, D.C.

(3) Shelton, John E., Chapter on Mercury, Mineral Facts and Problems, 1965, U. S. Bureau of Mines Bulletin 630, Department of the Interior, Washington, D.C., pp 573-581.

(4) Greenspoon, Gertrude N., Chapter on Mercury, Mineral Facts and Problems, 1970, U. S. Bureau of Mines Bulletin 650, Department of the Interior, Washington, D.C., pp 639-652.

(5) Development Document for Effluent Guidelines and Standards of Performance, Ore Mining and Dressing Industry (Draft), U. S. Environmental Protection Agency, Washington, D.C. (prepared by Calspan Corp., Buffalo, N. Y.), April 1975.

Crushing, Grinding, and Classifying

1. Function - Flotation is the most efficient way of concentrating mercury ores, but to date it has only been used on a pilot-plant scale. A commercial operation is scheduled to start in Nevada in late 1975. Grinding the crushed ore in a ball or rod mill in closed circuit with a classifier to free cinnabar from the gangue minerals is the first step in a flotation concentrator. In a Bureau of Mines pilot plant flotation of ore from the Hermes mercury mine in Idaho, classifier overflows of minus 48 to minus 65 mesh were sufficient to effect a high ratio of concentration in the flotation process, with mercury recoveries of about 90 percent.

2. Input Materials - Crushed ore and water.

3. Operating Parameters -

   Temperature: Ambient

   Pressure: Atmospheric

4. Utilities -

   Electrical energy: not known precisely; operation has yet to be started

5. Waste Streams -

   Dust, particulates from crushing operation

   Spills in the grinding-classification circuit

6. EPA Source Classification Code - None

7. References -

   (1) Private communication with members of the BCL staff who have conferred with producers.

   (2) Pennington, J. W., "Mercury--A Material Survey", U. S. Bureau of Mines Circular 7941 (1959), Department of the Interior, Washington, D.C.

(3) Shelton, John E., Chapter on Mercury, Mineral Facts and Problems, 1965, U. S. Bureau of Mines Bulletin 630, Department of the Interior, Washington, D.C., pp 573-581.

(4) Greenspoon, Gertrude N., Chapter on Mercury, Mineral Facts and Problems, 1970, U. S. Bureau of Mines Bulletin 650, Department of the Interior, Washington, D.C., pp 639-652.

(5) Development Document for Effluent Guidelines and Standards of Performance, Ore Mining and Dressing Industry (Draft), U. S. Environmental Protection Agency, Washington, D.C. (prepared by Calspan Corp., Buffalo, N. Y.), April 1975.

Flotation

1. **Function** - The flotation process (froth flotation) is one in which ore that is ground fine enough to free the mineral values from the gangue is agitated by rising air bubbles in cells containing water, frothing reagents, and other chemical reagents (such as collectors, activators, depressants, etc.) which cause the ore particles to be selectively wetted by the frothing reagent and become attached to the rising air bubbles. These collect into a froth on the surface where they are scraped off. In normal practice, a "rougher" concentrate is first produced and removed, and the tailings discarded. This "rougher" concentrate is then retreated in one or more "cleaner" flotation circuits to produce a finished concentrate and a tailing which is recycled to the "rougher" flotation circuit.

2. Input Materials - Ground ore from the grinding-classifier circuits, water, floatation reagents such as Dow froth 250 (polypropylene glycol methyl ethers), a frother; Z-11 (sodium isopropyl xanthate), a collector; and lime and sodium silicate, which are depressing agents.

3. Operating Parameters -

   Temperature: Ambient

   Pressure: Atmospheric

4. Utilities -

   Electrical energy: not known precisely but energy usage for analagous mineral sufide flotation processes (including condition and pumping) is about 2.52×10^8 joules/metric ton (7.0 kWhe/metric ton or 6.7×10^6 Btu/short ton) of ore.

5. Waste Streams -

   Mercury (cinnabar) in the tailings from the rougher cell. Also flotation reagents in the water in the tailings pond. In the one commercial installation planned, these reagents would be Dowfroth 250 (polypropylene glycol methyl ethers), a frother; Z-11 (sodium isopropyl xanthate), a collector; and lime and sodium silicate (depressing agents). There may also be finely divided suspended solids which may present removal problems. Solubilized, or dispersed colloidal or absorbed heavy metals may also be present.

6. EPA Source Classification Code - None

7. References -

(1) Private communication with members of the BCL staff who have conferred with producers.

(2) Pennington, J. W., "Mercury--A Material Survey", U. S. Bureau of Mines Circular 7941 (1959), Department of the Interior, Washington, D.C.

(3) Shelton, John E., Chapter on Mercury, Mineral Facts and Problems, 1965, U. S. Bureau of Mines Bulletin 630, Department of the Interior, Washington, D.C., pp 573-581.

(4) Greenspoon, Gertrude N., Chapter on Mercury, Mineral Facts and Problems, 1970, U. S. Bureau of Mines Bulletin 650, Department of the Interior, Washington, D.C., pp 639-652.

(5) Development Document for Effluent Guidelines and Standards of Performance, Ore Mining and Dressing Industry (Draft), U. S. Environmental Protection Agency, Washington, D.C. (prepared by Calspan Corp., Buffalo, N. Y.), April 1975.

Retorting

1. Function - Retorts are inexpensive installations for small operations treating 0.23 to 4.5 metric tons (1/4 to 5 short tons) of ore per day. Typically, they are manually-charged, cast-iron cylindrical (or D-shaped in cross section) vessels, 2.1 to 2.7 meters (7 to 9 feet) long and 25.4 to 20.5 cm (10 to 12 inches) in diameter. They are supported by brickwork or other masonry, and are heated with a fire box placed either below or to the side of the retort. Mercury gas discharges through a pipe at the closed end of the retort into an inclined, water-cooled tube condenser. Since only a limited amount of air is available to oxidize the sulfur, it is necessary to add lime or iron to the retort charge to combine with the sulfur in the ore. These additions are particularly necessary when the sulfur content of the ore is high.

   Mercury, dust, and soot collected in the condenser system are removed periodically and transported to a hoe table where the impure product is mixed with lime to recover the mercury. During this "hoeing" operation the mercury coalesces and flows into a sump at a low point in the table where it is collected and bottled in flasks. To increase yield, the residue from the hoe table is recycled by mixing it with the ore input into the retort.

2. Input Materials - Mercury Ore crushed to 3.8 - 5.1 cm (1-1/2 - 2 inch) maximum size

   Lime or iron to combine with sulfur in the ore. Lime additions to the hoeing table.

   Fuel for the retort fire box

3. Operating Parameters -

   Temperature: Retorting 377-399 C (710-750 F)

   Pressure: Controlled negative pressures are maintained in the system by means of draft gages to prevent the escape of fumes and dust.

4. Utilities -

Retorts are small inexpensive installations used by small operators. Fuel, coal, oil or bottled gas for retort heating is usually transported to the site. Rate of fuel usage per ton of ore is about the same as that for rotary furnaces (Process #7). Electric current is used only for central and plant auxiliaries.

5. Waste Streams -

Air Emissions: The flow of gas through the furnace and mercury condenser is controlled by an exhaust fan placed between the dust collector and the condenser. Any mercury remaining in the gas is recovered by passing the gases through wooden settling tanks (or alternatively, cooling towers) where recovery of mercury in the gas is achieved from a reduction in gas velocity and a slow percolation of gas through wetted baffles. Gases from this tank pass into the atmosphere through a wooden stack. Mercury losses to the atmosphere are very low when the temperature of the waste gas is kept below 49C (120F). Mercury recovery by this process usually equals or exceeds 98 percent. The major loss of mercury occurs in the stack gases. The emission factor for the retort operation is as follows:

0.001 Kg/metric ton (0.002 lb/short ton) of ore processed.

Condenser Water - The condenser cooling and wash water may contain metallic mercury which is potentially highly toxic, and thus requires lined lagoons for storing this waste water and any other process waste water.

Solid Waste - Minor amounts of mercury are entrained in the calcine residues, minor losses occur in dusts and spillage.

6. E.P.A. Source Classification Code - None

7. References same as Mercury - Cinnabar Deposits - Process No. 1 - Open Pit Mining.

Rotary Kiln Furnace Roasting of Mercury Ore

1. Function - Rotary kiln operation is most frequently used to liberate mercury vapor from ore (alternatively multiple hearth furnaces may be used, but they are not in common use in the United States). The kiln is essentially an insulated, fire-brick lined, rotating steel tube inclined slightly to the horizontal, with gas seals at each end. In operation, ore up to 4 cm (1-1/2 inches) in size, is fed into the kiln against a counter current flow of hot combustion gases. Calcine is discharged at the lower end of the kiln, while the mercury-laden gases then pass through a condenser where the mercury vapor is cooled below the dewpoint to form liquid mercury. Final traces of mercury vapor remaining in the gases from the condensors are removed in scavenger tanks or washers and collected. Rotary furnace installations vary greatly in capacity from 5.4-9.1 metric tons/day (6-10 short tons/day) [from 53 cm (21 inch) diameter by 6.1 meter (20 feet) long kiln] to 150-218 metric tons (165-240 short tons/day) [from a 183 cm (72 inch) diameter by 30.5 meter (100 feet) long kiln].

   Mercury, dust, and soot collected in the condenser system are removed periodically and transported to a hoe table where the impure product is mixed with lime to recover the mercury. During this "hoeing operation" the mercury coalesces and flows into a sump at a low point in the table where it is collected and bottled in flasks. To increase yield, the residue from the hoe table is returned to the rotary kiln for reprocessing.

2. Input Materials - Mercury ore crushed to a maximum 1-1/2 inch size

3. Operating Parameters -

Temperature: Gases from the rotary kiln enter the condenser at about 500C (930F) and exit at 125C (257F)

Pressure: Slightly below atmospheric. Negative pressures are maintained by blowers on the down stream side of the cyclone to prevent the escape of fumes and dust.

4. Utilities -

Roasting:
Residual Fuel Oil (Energy Equiv.) 4.4 x 10^8 joules/metric ton (122 kWhe/metric ton or 1.16 x 10^6 Btu/ton of ore).
Electrical Energy 0.16 x 10^8 joules/metric ton (4.4 kWhe/metric ton or 0.042 x 10^6 Btu/short ton) of ore

5. Waste Streams -

Air Emissions: The major emissions of mercury occur from the condenser stack. Others are from the hoe table ventilation air, and emissions from the hot calcine discharge. Emission factors for stack and hoeing operations are as follows:

Stack - 0.16 Kg/metric ton (0.031 lb/short ton) (6)
Hoeing Operations: 0.01 Kg/metric ton (0.02 lb/short ton) (6)

Water Effluent: The condenser cooling and wash-water can contain metallic mercury which is potentially highly toxic (Lined lagoons are recommended for storing this waste water). The chemical composition of waste water percolating through sinter tailings at a mine processing 200,000 tons of ore per year was as follows:

	mg/l
Nitrate	2.4
Chloride	63.8
Sulfate	2382.6
Bicarbonate	12.2
Carbonate	0
Sodium	186
Potassium	23.0
Calcium	289.6
Magnesium	294.4
Fluorides	1.7
Silica	18.0
Iron	0.02
Manganese	2.4

Boron	3.7
Cyanide	0.03
Lead	0.000
Arsenic	0.000
Copper	0.08
Mercury	0.02
Total Hardness	1950.0
pH	4.8-5.7

Solid Waste: Roasted sinter from the rotary kiln is transported to a tailings dump. As noted above under Water Effluents, some soluble mercury may be present. Other gangue constituents associated with cinnabar deposits which make up this sinter are carbonate and silicate minerals such as calcite, chalcedony, dolomite, opalite, quartz, and serpentine.

6. E.P.A. Source Classification Code - None

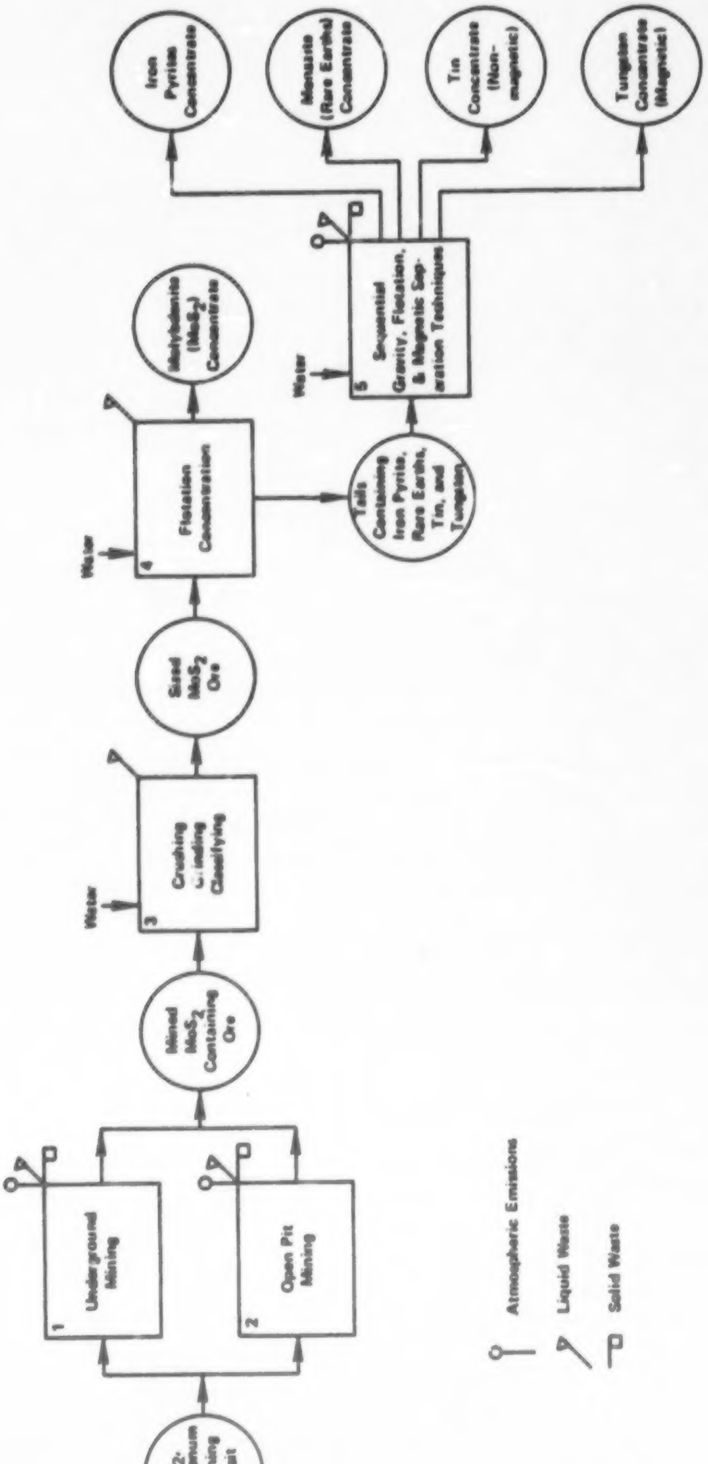
7. References - Same as Mercury - Cinnabar Deposits - Process #1, Open Pit Mining

Molybdenum

Molybdenum production in the United States amounts to about 56 percent of the total world production of around 200 million pounds per year. About 63 percent of the U.S. production is from primary sources, namely Rocky Mountain porphyry molybdenum deposits in Colorado and New Mexico, and the remainder as byproduct, principally from porphyry copper deposits in the Western States but also as byproduct from tungsten and uranium mining and beneficiating operations. The United States is completely self-sufficient in molybdenum and in fact exports molybdenum products upon demand (currently low). The greatest use of molybdenum is in the steelmaking industry in the form of molybdic oxide (>75 percent) addition for "moly-content" steels and in the form of ferromolybdenum. A relatively small portion of the total molybdenum production is reduced to the form of pure metal for use in molybdenum base alloys or as alloying addition in other nonferrous alloys. The reserves of molybdenum ores are quite large and should afford our continued self-sufficiency in this commodity for many years.

Two important mineral forms of molybdenum are molybdenite, MoS_2, and wulfenite, $PbMoO_4$. An example of a commercially important deposit of molybdenite is the Climax Mine in Colorado where the ore contains 0.34 percent molybdenite. Another molybdenite operation in the United States is that at Questa, New Mexico where the mineral wulfenite also is found. Molybdenite is the principal mineral for the recovery of molybdenum from all operations however. Molybdenite (sulfide) is the form associated with the concentrate produced by differential flotation at both molybdenum - and copper-producing operations.

Molybdenum


MoS$_2$-Molybdenum Containing Deposit
1
Underground Mining
2
Open Pit Mining
Mined MoS$_2$ Containing Ore
Water
3
Crushing Grinding Classifying
Sized MoS$_2$ Ore
Water
4
Flotation Concentration
Molybdenite (MoS$_2$) Concentrate
Tails Containing Iron Pyrite, Rare Earths, Tin, and Tungsten
Water
5
Sequential Gravity, Flotation, & Magnetic Separation Techniques
Iron Pyrites Concentrate
Monazite (Rare Earths) Concentrate
Tin Concentrate (Non-magnetic)
Tungsten Concentrate (Magnetic)
Atmospheric Emissions
Liquid Waste
Solid Waste

Underground Mining

1. Function - Molybdenum ore in the large underground mine at Climax, Colorado, is mined by block caving, a method in which the ore body is undercut to induce caving. Broken ore from the caved area flows down "finger raises" into concrete-lined slusher drifts. Haulage drifts are placed just below and perpendicular to these slusher drifts. Ore in the slusher drift is scraped into cars on the haulage level via "drawholes" connecting the slusher and haulage drifts.

   Smaller, vein-type deposits are mined by shrinkage and cut-and-fill stoping methods.

2. Input Materials - Explosives: 0.145 kg/metric ton (0.29 lb/short ton) of ore

3. Operating Parameters -

   Temperature: Ambient

   Pressure: Atmospheric

4. Utilities -

   Electrical energy: 0.21×10^8 joules/metric ton (6.0 kWhe/metric ton or 0.057×10^6 Btu/short ton) of ore
   Natural gas: 2 cu meters/metric ton (65 cu ft/short ton) of ore
   Liquid hydrocarbon fuels: 0.67 liter/metric ton (0.16 gal/short ton) of ore

5. Waste Streams -

   Mine water, on acid side from oxidation of sulfides, typical pH 4.5, may contain oil and grease, fluorides, and small amounts of copper, manganese, and zinc in solution. Mine water in the Climax installation goes to a tailing basin. Discharge from the tailing basin occurs during spring snow-melt runoff.

   Waste Rock from block-caving operations

6. EPA Source Classification Code - None

7. References -

(1) Private communication with members of the BCL staff who have conferred with producers.

(2) Development Document for Effluent Guidelines and Standards of Performance, Ore Mining and Dressing Industry (Draft), U. S. Environmental Protection Agency, Washington, D.C. (prepared by Calspan Corp., Buffalo, N. Y.), April 1975.

(3) Sheridan, Eugene T., Chapter on Molybdenum, Mineral Facts and Problems, 1970, Bureau of Mines Bulletin 650, U. S. Department of the Interior, Washington, D.C., pp 333-346.

(4) Holliday, R. W., Chapter on Molybdenum, Mineral Facts and Problems, 1965, Bureau of Mines Bulletin 630, U. S. Department of the Interior, Washington, D.C., pp 595-605.

(5) Hallowell, J. B., et al., Water Pollution Control in the Primary Non-Ferrous Industry, Vol II, Aluminum, Mercury, Gold, Silver, Molybdenum, and Tungsten, prepared for the Office of Research and Monitoring, U. S. Environmental Protection Agency, Washington, D.C., EPA-R2-73-247b, September 1973.

Open Pit Mining

1. Function - The two largest deposits of molybdenite, MoS_2, in the U. S. are mined by open pit methods in much the same manner as that outlined for copper. (Both require the removal of large quantities of overburden.) One of these deposits, that at Climax, Colorado, is mined by both open pit and underground methods; production from this open pit is relatively new, starting in 1973. The other large open pit deposit located at Questa, New Mexico, also contains wulfenite, lead molybdate, $PbMoO_4$. Both deposits contain some ferrimolybdate, $FeMoO_3 \cdot H_2O$. The Climax, Colorado, deposit also contains tungsten as wolframite, rare earth oxides in the mineral monazite, tin as cassiterite, and iron pyrites, all of which are recovered as by-products.

2. Input Materials - Explosives (ammonium-nitrate-fuel oil): 0.125 kg/metric ton (0.25 lb/short ton) of ore (based on analagous open pit copper mine operations)

3. Operating Parameters -

   Temperature: Ambient

   Pressure: Atmospheric

4. Utilities (based on analagous open pit copper mine operations) -

   Electrical energy: 0.22×10^8 joules/metric ton (6.1 kWhe/metric ton or 0.058×10^6 Btu/short ton) of ore
   Natural gas: 0.047 cu meter/metric ton (1.5 cu ft/short ton) of ore
   Diesel fuels: 1.13 liters/metric ton (.27 gal/short ton) of ore

5. Waste Streams -

   Dust, particulates from blasting, loading, etc.

   No mine water is produced at the large open pit mine in Questa, New Mexico.

   Suspended solids and dissolved ore constituents in runoff waste water.

Impoundment of waste water in mountain areas subject to spring flooding

Oxidation of exposed sulfides produces low pH acid waste water containing increased soluble material.

Blasting decomposition products and oil and grease may be present in waste water effluent.

Percolation of water through overburden and waste stockpile contributes to increased dissolved materials from these sources.

There is a considerable storage problem with large amounts of overburden in mountainous country.

6. EPA Source Classification Code - None

7. References -

(1) Private communication with members of the BCL staff who have conferred with producers.

(2) Development Document for Effluent Guidelines and Standards of Performance, Ore Mining and Dressing Industry (Draft), U. S. Environmental Protection Agency, Washington, D.C. (prepared by Calspan Corp., Buffalo, N. Y.), April 1975.

(3) Sheridan, Eugene T., Chapter on Molybdenum, Mineral Facts and Problems, 1970, Bureau of Mines Bulletin 650, U. S. Department of the Interior, Washington, D.C., pp 333-346.

(4) Holliday, R. W., Chapter on Molybdenum, Mineral Facts and Problems, 1965, Bureau of Mines Bulletin 630, U. S. Department of the Interior, Washington, D.C., pp 595-605.

(5) Hallowell, J. B., et al., Water Pollution Control in the Primary Non-Ferrous Industry, Vol II, Aluminum, Mercury, Gold, Silver, Molybdenum, and Tungsten, prepared for the Office of Research and Monitoring, U. S. Environmental Protection Agency, Washington, D.C., EPA-R2-73-247b, September 1973.

Crushing, Grinding, and Classifying

1. Function - Both the primary molybdenite ores and the copper sulfide ores containing molybdenite are concentrated by flotation. Accordingly, these ores are crushed, then ground in closed circuit with a classifier (typically, a cone classifier) so that the molybdenite mineral particles are physically separated from associated gangue. Regrinding in circuit with a classifier of oversize from the intermediate flotation "cleaner" tailings classifiers is usual practice in molybdenite flotation.

2. Input Materials - Mined ore, water

3. Operating Parameters -

   Temperature: Ambient

   Pressure: Atmospheric

4. Utilities -

   Electrical energy: for crushing, 0.064×10^8 joules/metric ton (1.8 kWhe/metric ton or 0.017×10^6 Btu/short ton) of ore; for grinding, 0.45×10^8 joules/metric ton (12.6 kWhe/metric ton or 0.12×10^6 Btu/short ton) of ore

5. Waste Streams -

   Dust, particulates from multistage crushings

   Spills in grinding-classification circuit.

6. EPA Source Classification Code - None

7. References -

   (1) Private communication with members of the BCL staff who have conferred with producers.

   (2) Development Document for Effluent Guidelines and Standards of Performance, Ore Mining and Dressing Industry (Draft), U. S. Environmental Protection Agency, Washington, D.C. (prepared by Calspan Corp., Buffalo, N. Y.), April 1975.

(3) Sheridan, Eugene T., *Chapter on Molybdenum*, Mineral Facts and Problems, 1970, Bureau of Mines Bulletin 650, U. S. Department of the Interior, Washington, D.C., pp 333-346.

(4) Holliday, R. W., *Chapter on Molybdenum*, Mineral Facts and Problems, 1965, Bureau of Mines Bulletin 630, U. S. Department of the Interior, Washington, D.C., pp 595-605.

(5) Hallowell, J. B., et al., *Water Pollution Control in the Primary Non-Ferrous Industry, Vol II, Aluminum, Mercury, Gold, Silver, Molybdenum, and Tungsten*, prepared for the Office of Research and Monitoring, U. S. Environmental Protection Agency, Washington, D.C., EPA-R2-73-247b, September 1973.

Flotation

1. Function - Molybdenite, MoS_2, is recovered from ground ore by flotation. Flotation is usually carried out at alkaline pH, typically 8.5 for molybdenite. It is controlled with lime. Reagents used include collectors which are reagents that are absorbed onto the molybdenite particle surfaces and make these surfaces hydrophobic, frothers such as pine oil, to aid the collector-coated minerals to cling to rising air bubbles, and depressants such as sodium cyanide, to supress the flotation of minerals such as pyrite that might be associated with molybdenite. Where there are no by-product values in the ore, the flotation is carried out in three separate steps: roughing, cleaning, and recleaning. Several stages, each necessitating regrinding and recycling, comprise each step. Final concentrates are dewatered and dried for shipment to plants for further processing onto molybdenum products.

2. Input Materials - Ground ore, water, flotation reagents, lime for pH control

3. Operating Parameters -

   Temperature: Ambient

   Pressure: Atmospheric

   pH of flotation slurry: 8.5

4. Utilities (includes energy costs of beneficiation of associated mineral values) -

   Electrical energy: for flotation; 0.19×10^8 joules/metric ton or 0.050×10^6 Btu/short ton) of ore; for pumping, tailings disposal, gravity classifiers, etc., 0.18×10^8 joules/metric ton (5.0 kWhe/metric ton or 0.047×10^6 Btu/short ton) of ore

5. Waste Streams -

   Tailings from molybdenite flotation have a pH of about 8.5; the pH is controlled with lime additions. They also contain surfactants, cyanides (depressants), oils, and greases, complex organic reagents such as xanthates and amines. Molybdenum is soluble as the molybdate anion in basic solutions.

The solids in the tailings are finely ground. Therefore dissolution of soluble constituents in the ore is intensified. The suspended solids content would also tend to be high. Since the ore is so lean, about 0.34% MoS_2, solid tailings are voluminous.

Spring thaws in mountain areas may cause tailings pond overflow.

6. EPA Source Classification Code - None

7. References -

(1) Private communication with members of the BCL staff who have conferred with producers.

(2) Development Document for Effluent Guidelines and Standards of Performance, Ore Mining and Dressing Industry (Draft), U. S. Environmental Protection Agency, Washington, D.C. (prepared by Calspan Corp., Buffalo, N. Y.), April 1975.

(3) Sheridan, Eugene T., Chapter on Molybdenum, Mineral Facts and Problems, 1970, Bureau of Mines Bulletin 650, U. S. Department of the Interior, Washington, D.C., pp 333-346.

(4) Holliday, R. W., Chapter on Molybdenum, Mineral Facts and Problems, 1965, Bureau of Mines Bulletin 630, U. S. Department of the Interior, Washington, D.C., pp 595-605.

(5) Hallowell, J. B., et al., Water Pollution Control in the Primary Non-Ferrous Industry, Vol II, Aluminum, Mercury, Gold, Silver, Molybdenum, and Tungsten, prepared for the Office of Research and Monitoring, U. S. Environmental Protection Agency, Washington, D.C., EPA-R2-73-247b, September 1973.

By-Product Recovery by Combined Gravity-Flotation Magnetic Separation-Concentration Techniques

1. Function - The largest U. S. deposit of molybdenite ore at Climax, Colorado, contains iron pyrite, rare earth metals in monozite, tungsten as wolframite, and tin as cassiterite, which are separated by a combination of gravity, flotation, and magnetic separation methods. Tailings from the rougher flotation are routed to Humphrey spirals; the concentrated heavy fractions sluiced from the Humphrey spirals are then treated by flotation to produce a pyrite concentrate which is marketed after being dewatered and dried. Tailings from the pyrite flotation machine are tabled to produce a concentrate containing monazite, tin, and tungsten. This concentrate, in turn, is treated by flotation to produce a monazite concentrate comprising rare earth metal phosphates. The tailings from the monazite flotation are dewatered and dried, then magnetically separated to produce a nonmagnetic tin concentrate and a magnetic tungsten concentrate.

2. Input Materials - Slurries of tailings from the molybdenite rougher flotation cells, water flotation agents such as the following in pyrite flotation: sulfuric acid, (0.018 Kg/metric ton of ore milled), Z-3 xanthate collector (0.0005 Kg/metric ton of ore milled), and Dowfroth 50 frother (0.0001 Kg/metric ton of ore milled). In monazite flotation the following reagents are used: "Armac C" collector, starch and sulfuric acid - all at the rate of 0.0005 Kg/metric ton of ore milled.

3. Operating Parameters -

   Pyrite is removed from the heavy fractions from the Humphrey spirals by flotation at pH 4.5. The tailings from this step are tabled to further concentrate the heavy fractions. The pH of the table concentrate is adjusted to 1.5 and its temperature raised to 70 C (158 F) for the flotation of monazite. Tailings from this flotation step are dewatered, dried, and fed to magnetic separators which yield tin (cassiterite) and tungsten (wolframite).

4. Utilities (includes energy cost of molybdenite separation) -

   Electrical energy: for flotation, 0.19×10^8 joules/metric ton or 0.050×10^6 Btu/short ton) of ore; for pumping, tailings disposal, gravity classifiers, etc., 0.18×10^8 joules/metric ton (5.0 kWhe/metric ton or 0.047×10^6 Btu/short ton) of ore

   The magnetic separators require about 0.04×10^8 joules/metric ton (1.1 kWhe/metric ton or 0.011×10^6 Btu/short ton) of feed.

5. Waste Streams -

The tailings from the molybdenite flotation rougher comprising 97 percent of the ore input enter the by-products plant. Reagents used for flotation include sulfuric acid for pH regulation, xanthates and other collectors, starch (as a depressant for WO_2), and Dowfroth 250, a frothing agent. Effluents from by-products plant flotation machines will have an increased amount of heavy metals in solution because of the increase of the acidity of the flotation slurries. Iron and manganese in solution are high. Total suspended solids are also high.

6. EPA Source Classification Code - None

7. References -

(1) Private communication with members of the BCL staff who have conferred with producers.

(2) Development Document for Effluent Guidelines and Standards of Performance, Ore Mining and Dressing Industry (Draft), U. S. Environmental Protection Agency, Washington, D.C. (prepared by Calspan Corp., Buffalo, N. Y.), April 1975.

(3) Sheridan, Eugene T., Chapter on Molybdenum, Mineral Facts and Problems, 1970, Bureau of Mines Bulletin 650, U. S. Department of the Interior, Washington, D.C., pp 333-346.

(4) Holliday, R. W., Chapter on Molybdenum, Mineral Facts and Problems, 1965, Bureau of Mines Bulletin 630, U. S. Department of the Interior, Washington, D.C., pp 595-605.

(5) Hallowell, J. B., et al., Water Pollution Control in the Primary Non-Ferrous Industry, Vol II, Aluminum, Mercury, Gold, Silver, Molybdenum, and Tungsten, prepared for the Office of Research and Monitoring, U. S. Environmental Protection Agency, Washington, D.C., EPA-R2-73-247b, September 1973.

Nickel

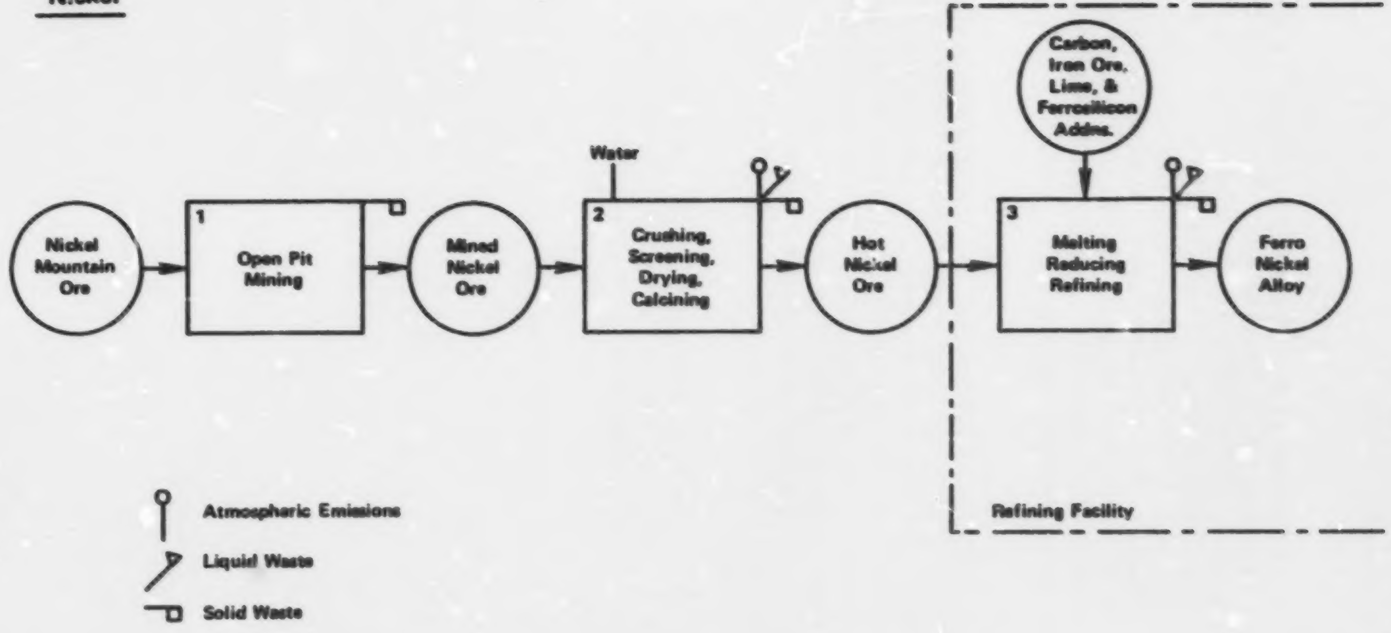
The amount of nickel consumed within the United States is approximately one-half of the free world production. While a large proportion of the free-world nickel production takes place in North America (Canada), the production of nickel in the U.S. is minimal. The mining of the ore for this commodity, its conditioning, and the smelting of this domestic ore to ferronickel is done at only one place in the United States--near Riddle, Oregon. The Hanna Mining Company and the Hanna Nickel Smelting Company, both daughter companies of Hanna Steel Comaany as the names suggest, are the only operators.

The mineral garnierite, $H_2(Ni, Mg) SiO_4$, is the nickel containing member of a weathered peridotite-type rock found on Nickel Mountain, Riddle, Oregon. The garnierite bearing rock which averages about 1.2 percent nickel is the ore body being exploited by Hanna. The intensity of the green color of the rock is directly proportional to the nickel content (other nickel minerals are associated with the garnierite in small amounts) and efforts begin at the mine to sort and blend ore by color to produce a uniform feed to the melting furnace (smelting).

The Hanna Company also produces ferrosilicon in an associated operation for use in reducing and refining the ore to the ferronickel end product. Coke, lime, and iron ore also are added in the refining operation.

The product of the Hanna Companies' operations is ferronickel alloy.

Nickel


Nickel Mountain Ore
1
Open Pit Mining
Mined Nickel Ore
Water
2
Crushing, Screening, Drying, Calcining
Hot Nickel Ore
Carbon, Iron Ore, Lime, & Ferrosilicon Addns.
3
Melting Reducing Refining
Ferro Nickel Alloy
Refining Facility
Atmospheric Emissions
Liquid Waste
Solid Waste

Open Pit Mining

1. Function - The Hanna Mining Company mines nickel ore in an open pit operation at Nickel Mountain near Riddle, Oregon. The mineral garnierite, $H_2(Ni,Mg)SiO_4$, and several associated minerals occur in altered peridotite. Ores average around 1.2 percent nickel.

2. Input Materials - Ore at Nickel Mountain is dug without blasting.

3. Operating Parameters -

   Temperature: Ambient

   Pressure: Atmospheric

4. Utilities -

   No energy is required to tram the ore, rather the electric generators used to brake the tram cars in their 610 meter (2000 ft) descent to the smelter generate electric power.

5. Waste Streams -

   Ores do not have a tendency to dust because of high moisture content.

   Mine water runoff in prolonged wet weather during the winter season is voluminous, as much as 2,180 cu meters/day (576,000 gal/day) to the impoundment.

   Boulders of residual rock are rejected at the mine. Rejects of submarginal ore after crushing are also made at the mine.

6. EPA Source Classification Code - None

7. References -

   (1) Private communication with members of the BCL staff who have conferred with producers.

(2) Development Document for Effluent Guidelines and Standards of Performance, Ore Mining and Dressing Industry (Draft), U. S. Environmental Protection Agency, Washington, D.C. (prepared by Calspan Corp., Buffalo, N. Y.), April 1975.

(3) Ware, Glen C., Chapter on Nickel, Mineral Facts and Problems, 1965, Bureau of Mines Bulletin 630, U. S. Department of the Interior, Washington, D.C., pp 607-619.

(4) Reno, Horace T., Chapter on Nickel, Mineral Facts and Problems, 1970, Bureau of Mines Bulletin 650, U. S. Department of the Interior, Washington, D.C., pp 347-360.

NICKEL - NICKEL MOUNTAIN ORES BENEFICATION PROCESS NO. 2

Crushing, Screening, Drying, and Calcining

1. Function - Ore is crushed at the mine and screened; plus 7.6 cm (3-inch) oversize is lower grade and is rejected. Undersize is aerotrammed to the mill where it is stockpiled and blended to obtain uniformity and, since it contains 17-25 percent moisture at this point, it is dried in large rotary kilns. Drying and tumbling in a rotary kiln breaks up the valuable minerals in the ore charge and it is screened again following drying; plus 1.91 cm (3/4-inch) material is rejected at this point; plus 0.79 cm (5/16-inch) material is re-crushed and recycled; and minus 0.79 cm (5/16-inch) material is classified as it is needed for the next step, electric furnace reduction, into plus and minus 0.83 mm (20-mesh) material. The plus 0.83 mm (20-mesh) material is calcined in a rotary kiln to remove water of crystallization from the concentrate, and to preheat it for charging into the electric furnace. The minus 0.83 mm (20-mesh) material is calcined and preheated in a multihearth furnace.

2. Input Materials - Broken ore at the mine site and water

3. Operating Parameters -

   The calciners operate as preheaters for the electric furnace charge so that temperatures are higher than normal, about 650-700 C (1200-1300 F).

4. Utilities -

   No energy is required for crushing and screening at the mine since all the energy used there is produced by generators in the descending tram cars.

   Drying consumes 144 x 10^8 joules/metric ton (3990 kWhe/metric ton or 38.0 x 10^6 Btu/short ton) of ferronickel (46% Ni).

   Calcining and preheating consumes 129 x 10^8 joules/metric ton (3590 kWhe/metric ton or 34.2 x 10^6 Btu/short ton) of ferronickel (46% Ni).

5. Waste Streams -

Beneficiation is dry. Emission rates from the drying, regrinding, and calcining steps are high. Dust emission control devices are used on the calciners.

Water is used for belt washing and in wet scrubbers.

Oversize rejects, above 7.6 cm (3-inch) at mine screens, and above 1.91 cm (3/4-inch) at drying screens, are voluminous.

6. EPA Source Classification Code - None

7. References -

(1) Private communication with members of the BCL staff who have conferred with producers.

(2) Development Document for Effluent Guidelines and Standards of Performance, Ore Mining and Dressing Industry (Draft), U.S. Environmental Protection Agency, Washington, D.C. (prepared by Calspan Corp., Buffalo, N.Y.), April 1975.

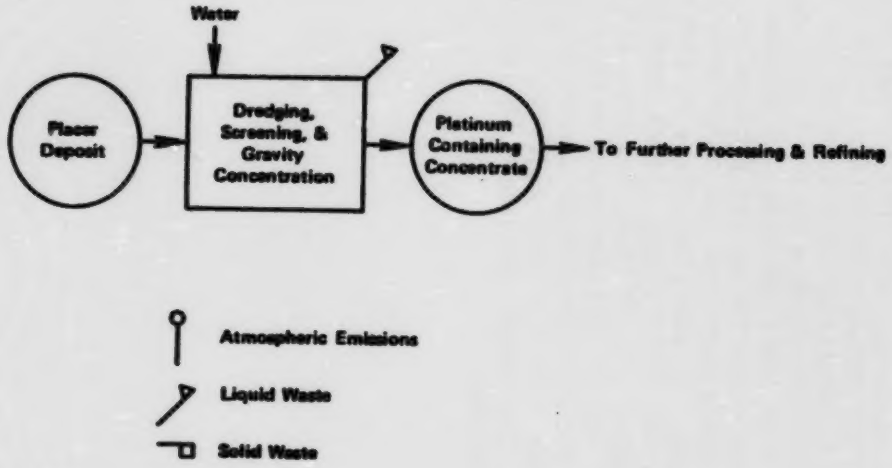
(3) Ware, Glen C., Chapter on Nickel, Mineral Facts and Problems, 1965, Bureau of Mines Bulletin 630, U.S. Department of the Interior, Washington, D.C., pp 607-619.

(4) Reno, Horace T., Chapter on Nickel, Mineral Facts and Problems, 1970, Bureau of Mines Bulletin 650, U.S. Department of the Interior, Washington, D.C., pp 347-360.

Platinum Group Metals

The United States is almost totally dependent on import platinum and platinum-group metals since our production is only about 1 percent of consumption (consumption is about 1.4 million ounces per year). Platinum and palladium are the best known and most widely used members of the platinum group; the other members iridium, osmium, rhodium, and ruthenium, are less abundant. The only current primary platinum recovery operation in the U.S. is located in Alaska. A custom concentrator in California purchases platinum-group ores for benefication along with their coproduct or byproduct platinum-group ores from their own mine. Elsewhere in the United States, platinum-group concentrates are produced as coproduct or byproduct with gold and silver from one other mine in California and from one in Nevada. In addition, there is platinum-group metal recovery from the electrolytic slimes associated with copper recovery. Copper ores in Utah, Arizona, and New Mexico contain small quantities of platinum group metals--chiefly palladium and platinum. Platinum-group metals recovery is principally palladium and platinum from U.S. ores although a fairly new operation in Moro County, California is recovering osmium and iridium in appreciable quantities.

Platinum Group Metals


Water
Placer Deposit
Dredging, Screening, & Gravity Concentration
Platinum Containing Concentrate
To Further Processing & Refining
Atmospheric Emissions
Liquid Waste
Solid Waste

PLATINUM GROUP METALS - PLACER DEPOSITS

PROCESS NO. 1

Dredging, Screening, Jigging, Tabling, and Magnetic Separation

1. **Function** - With the exception of the recently discovered primary platinum veins in Rickey Canyon, Moro County, California (the first primary platinum vein in the United States), which will be mined first by open pit methods and later by underground methods, the only primary mining of platinum in the United States is the single dredging operation in the Goodnews Bay District of Alaska. Most of the platinum group metals in the U.S. are produced as byproducts of gold and copper refining. It happens that the mineralization of the "platinum" deposit in Moro County, California, also includes the rare earth group of metals, gold and silver, tantalum, and columbium, with rare earths having the principal mineral value at this early stage of development.

   In the Alaskan dredging operation, dredged gravels are screened, jigged, and tabled to separate the heavy minerals from thelighter gangue. Chromate and magnetite are separated from the platinum group minerals by magnetic separation. The separated platinum group concentrates are then screened to a series of uniformly sized cuts, all of which are passed through blowers to remove any remaining light fractions. Concentrates assaying 90 percent platinum group metals and gold are produced. These are shipped to a refinery.

2. **Input Materials** - Gravel and water from a placer deposit

3. **Operating Parameters** -

   Temperature: Ambient

   Pressure: Atmospheric

4. **Utilities** -

   Electric Energy: (Dredging, screening, jigging, and tabling--based on analogous operation) 1.37 x 10^8 joules/metric ton (38 kWhe/metric ton or 0.36 x 10^6 Btu/short ton) of gravel. (Magnetic separation) About 0.04 x 10^8 joules/metric ton (1.1 kWhe/metric ton or 0.01 x 10^6 Btu/short ton) of concentrate

5. **Waste Streams** -

   Mining and milling in a dredge operation cannot be considered separately since the wet mill on board the dredge discharges to the dredge pond.

No reagents are used in the milling process.

The principal waste constituent from a dredge operation is suspended solids.

6. EPA Source Classification Code - None

7. References -

(1) Private communication with members of the BCL staff who have conferred with producers.

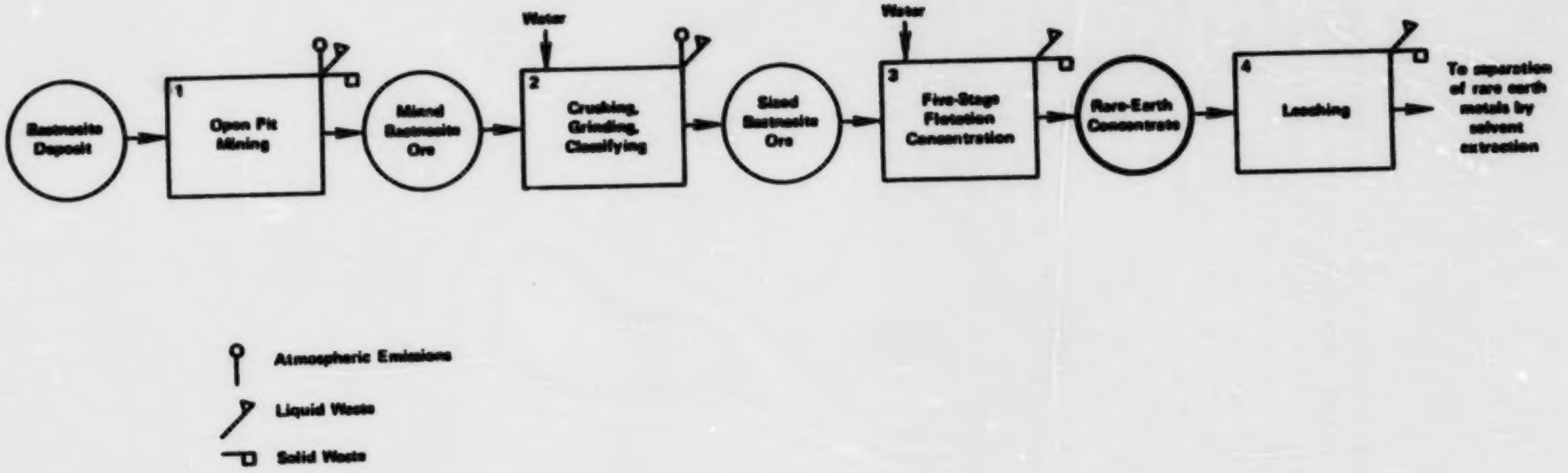
(2) Development Document for Effluent Guidelines and Standards of Performance, Ore Mining and Dressing Industry (Draft), U.S. Environmental Protection Agency, Washington, D.S. (prepared by Calsfan Corp., Buffalo, N.Y.), April 1975.

(3) Platinum Metals Group Supply in Critical Materials, Commodity Action Analysis, Aluminum, Chromium, Platinum, Palladium; First edition, Office of Mineral Policy Development, U.S. Department of the Interior, March 1975.

Rare Earth Metals

The rare-earth metals group usually is considered to include the elements with atomic numbers 57 through 71 as follows: cerium, dysprosium, erbium, europium, gadolinium, holmium, lanthanum, lutetium, neodynium, praseodynium, promethium, samarium, terbium, thulium, and ytterbium. Some groups in industry include the metals yttrium and scandium in the rare-earth group although only yttrium has the chemical characteristics of the rare-earths. Cerium and lanthanum are the most abundant of the rare-earth group in U. S. ores. The United States is self-sufficient in rare-earth metals-the California deposits of bastnasite and other rare-earth minerals are the world's largest known ore bodies of this type. Production is from these deposits and from byproduct rare-earth oxide minerals from the titanium and phosphate production in the Southeastern U.S. and from molybdenum production in Colorado. The annual domestic consumption of rare-earth oxides is currently about 13,700 tons.

Rare-Earth Metals (Thorium By-Product at Refinery)


Bastnasite Deposit
1
Open Pit Mining
Mined Bastnasite Ore
Water
2
Crushing, Grinding, Classifying
Sized Bastnasite Ore
Water
3
Five-Stage Flotation Concentration
Rare-Earth Concentrate
4
Leaching
To separation of rare earth metals by solvent extraction
Atmospheric Emissions
Liquid Waste
Solid Waste

RARE EARTH METALS - DEPOSITS CONTAINING
RARE EARTHS: BASTNASITE

PROCESS NO. 1

Open-Pit Mining

1. Function - Rare earth metals are produced from several sources. Over 90 percent of U.S. production comes from the bastnasite deposits of the Mountain Pass Area in San Bernadino County, California. Bastnasite is a fluorcarbonate mineral containing primarily cerium, lanthanum, neodymium, and praseodynium, plus small amounts of samarium, gadolinium, and europium.

   Rare earths also occur in monazite $(Ce,La,Th,Y)PO_4$; considerable amounts of it are recovered as a by-product from titanium open-pit mining and milling operations in Florida and Georgia. These are covered in the titanium section.

   There is a platinum vein deposit which contains rare earths that is being developed at Rickey Canyon in Moro County, California. This is a complex deposit which contains gold and silver, tantalum and columbium besides platinum and the rare earths. At present stage of development, the rare earths represent the principal mineral value. The mine has been developed by underground methods, but open pit-mining methods will supercede these. Thus, practically all of the rare earths produced in the United States will be mined by ordinary open-pit methods. In the case of the bastnasite deposit at Mountain Pass, California, ore is blasted, loaded into trucks by power shovels, and trucked about a quarter of a mile to the mill.

2. Input Materials - Explosives 0.75 kg/metric (1.5 lb/short ton) of ore

3. Operating Parameters -

   Temperature - Ambient

   Pressure - Atmospheric

4. Utilities -

   Electric Energy: 0.14 x 10^8 joules/metric ton (4.0 kWhe/metric ton or 0.038 x 10^6 Btu/short ton) of ore

   Fuel Oil: 23.4 liters/metric ton (5.6 gal/short ton) of ore

5. Waste Streams -

Dust, particulate in loading and blasting

Dust controlled by water spraying

No mine discharge currently exists at the Mountain Pass, California open-pit mine

Waste rock storage

6. EPA Source Classification Code - None

7. References -

(1) Private communication with members of the BCL staff who have conferred with producers.

(2) Development Document for Effluent Guidelines and Standards of Performance, Ore Mining and Dressing Industry (Draft), U. S. Environmental Protection Agency, Washington, D.C. (Prepared by Calspan Corp., Buffalo, N. Y.), April 1975.

(3) The Rare Earth Elements, Yttrium and Thorium; A Materials Survey, Bureau of Mines Information Circular No. 8476, Bureau of Mines, U. S. Department of the Interior, 1971.

Crushing, Grinding, Classifying, and Conditioning

1. Function - Crushing, grinding, and classifying are done at both the 2720 metric ton (3000 - short tons)-per-day-concentrator at Mountain Pass, Riverside County, California, and the 91 metric ton -(100 - short tons)-per-day concentrator at Rickey Canyon, Mono County, California. The latter handles ore from a new mine not yet in full production.

   The crushing, grinding, and classifier section at the Mountain Pass concentrator consists of a primary jaw crusher in series with a Symons cone crusher, from which a 1.6 cm (5/8-inch) feed passes to a 1.8 - by 3.0-meter (6- by 10-foot) rod mill. This produces a minus-1.65 mm (10-mesh) material which is fed to a Dorr classifier in closed circuit with a 2.7-meter (9-foot) by 1.5-meter (5-foot) conical ball mill. The classifier overflow, containing 52 percent solids which are 96 percent minus 0.15 mm (100 mesh) flows to 3 heating agitators where the pulp is heated by stages to 93 C (200 F) by using waste heat from a diesel generating plant, supplemented by steam from a boiler. A fourth agitator is used to cool the slurry to 60 C (140 F) before pumping it to rougher flotation. Heating is necessary to condition the rare earth containing mineral, bastnasite, for flotation.

2. Input Materials - Mined bastnasite ore, water, and steam

3. Operating Parameters -

   Temperature: Ground pulp from the classifier overflow is heated to 93 C (200 F) and then cooled to 60 C (140 F) to condition it for flotation

   Pressure: Atmospheric

4. Utilities -

Electric Energy: Bastnasite ore preparation, crushing, 0.21 x 10^8 joules/metric ton (5.9 kWhe/metric ton or 0.056 x 10^6 Btu/short ton) of ore; grinding, 0.62 x 10^8 joules/metric tons (17.3 kWhe/metric ton or 0.16 x 10^6 Btu/short ton) of ore; conditioning, 0.032 x 10^8 joules/metric ton (0.9 kWhe/metric ton or 0.008 x 10^6 Btu/short ton) of ore

Reserve Fuel Oil: (for steam boiler) Bastnasite ore preparation (conditioning) 1.1 liters/metric ton (0.27 gal/short ton) of ore

5. Waste Streams -

Dust, particulates in crushing operation

Spills in grinding-classifier-heat agitator cycle

6. EPA Source Classification Code - None

7. References -

(1) Private communication with members of the BCL staff who have conferred with producers.

(2) Development Document for Effluent Guidelines and Standards of Performance, Ore Mining and Dressing Industry (Draft), U. S. Environmental Protection Agency, Washington, D.C. (Prepared by Calspan Corp., Buffalo, N. Y.), April 1975.

(3) The Rare Earth Elements, Yttrium and Thorium; A Materials Survey, Bureau of Mines Information Circular No. 8476, Bureau of Mines, U. S. Department of the Interior, 1971.

RARE EARTH METALS - DEPOSITS CONTAINING RARE EARTHS; BASTNASITE

PROCESS NO. 3

Flotation

1. Function - Ground bastnasite ore from the Mountain Pass area of San Bernadino County, California is preheated to 95 C (200 F) and cooled to 60 C (140 F) to condition it for flotation. An oleic-olein collector, Orzan A, and silicic acid are added to the slurry during the conditioning. Flotation is initiated in four Fagergren and eight Agitair rougher machines which produces a tailing for discard. Barite is depressed during flotation, and the froth is cleaned in five stages of Denver cells. Froth from each cleaner advances to the next stage and tailing is recycled countercurrently to the preceding cell. The final flotation concentrate contains 63 percent rare earth oxides. The operation at Rickey Canyon, Mono County, California at present consists of a flotation circuit augmented by various gravity concentration and other separation steps to separate the platinum, gold and silver, tantalite, and columbite from the rare earths in the complex ore body which is being developed. The wet gravity methods in current use will be replaced by air-gravity separation methods in the near future.

2. Input Materials - Ground ore conditioned by heating for flotation, Orzan A (oleic-olein), silicic acid, and water.

3. Operating Parameters -

   Temperature: 60 C (140 F)

   Pressure: Atmospheric

4. Utilities -

   Electric Energy: Bastnasite flotation - 0.38 x 10^8 joules/metric ton (10.6 kWhe/metric ton or 0.10 x 10^6 Btu/short ton) of ore; heat conditioning, bastnasite ore - 1.13 liters/metric ton (0.27 gal/short ton) of ore

5. Waste Streams -

   Flotation tailings are discharged to a tailing pond, clarified, and recycled back to the flotation circuit. The mill at Mountain Pass is in a desert area and water is scarce.

Reagents used in the flotation circuit are as follows

Frother	Methyl, sobutyl carbinol
Collector	N-80 oleic acid
pH Modifier	Sodium carbonate (to pH 8.95)
Depressants	Orzan, sodium silicofluoride
Conditioning Agent	Molybdenum compound

High total solids and high fluoride content in waste water

6. EPA Source Classification Code - None

7. References -

(1) Private communication with members of the BCL staff who have conferred with producers.

(2) Development Document for Effluent Guidelines and Standards of Performance, Ore Mining and Dressing Industry (Draft), U. S. Environmental Protection Agency, Washington, D.C. (Prepared by Calspan Corp., Buffalo, N. Y.), April, 1975.

(3) The Rare Earth Elements, Yttrium and Thorium; A Materials Survey, Bureau of Mines Information Circular No. 8476, Bureau of Mines, U. S. Department of the Interior, 1971.

RARE EARTH METALS - DEPOSITS CONTAINING
RARE EARTHS; BASTNASITE

PROCESS NO. 4

Leaching

1. **Function** - Leaching the final bastnasite flotation concentrate, which contains 63 percent rare earth oxides (REO), in 10 percent hydrochloric acid, removes calcium and strontium carbonates and raises the grade to 72 percent REO. A further beneficiation to over 92 percent REO is accomplished by drying and calcining the leached concentrate in the solvent-extraction plant. This eliminates carbonate, leaving essentially a mixture of rare-earth oxides and fluorides.

2. **Input Materials** - Flotation concentrates, hydrochloric acid

3. **Operating Parameters** -

   Temperature: Ambient

   Pressure: Atmospheric

4. **Utilities** -

   Electric Energy: Leaching - 0.14 x 10^8 joules/metric (4.0 kWhe/metric ton or 0.038 x 10^6 Btu/short ton) of flotation concentrate; thickening and filtering - 0.004 x 10^8 joules/metric ton (0.12 kWhe/metric ton or 0.001 x 10^6 Btu/short ton) of flotation concentrate

5. **Waste Streams** -

   The leach dissolves calcite ($CaCO_3$) strontianite ($SrCO_3$), and barite ($BaSO_4$) from the concentrates. Chlorides in solution (from the acid leach) are extremely high, 54,000 mg/l. Leach waters are impounded with waste water from the solvent exchange plant. Tellurium, not known to be present in the ore, is dissolved in the combined waste stream at rather high concentration, 3.4 mgl. Leach circuit wastes are kept separated from flotation circuit wastes as the very high dissolved solid concentrations would interfere with flotation.

6. **EPA Source Classification Code** - None

7. References -

(1) Private communication with members of the BCL staff who have conferred with producers.

(2) Development Document for Effluent Guidelines and Standards of Performance, Ore Mining and Dressing Industry (Draft), U. S. Environmental Protection Agency, Washington, D.C. (Prepared by Calspan Corp., Buffalo, N. Y.), April, 1975.

(3) The Rare Earth Elements, Yttrium and Thorium; A Materials Survey, Bureau of Mines Information Circular No. 8476, Bureau of Mines, U. S. Department of the Interior, 1971.

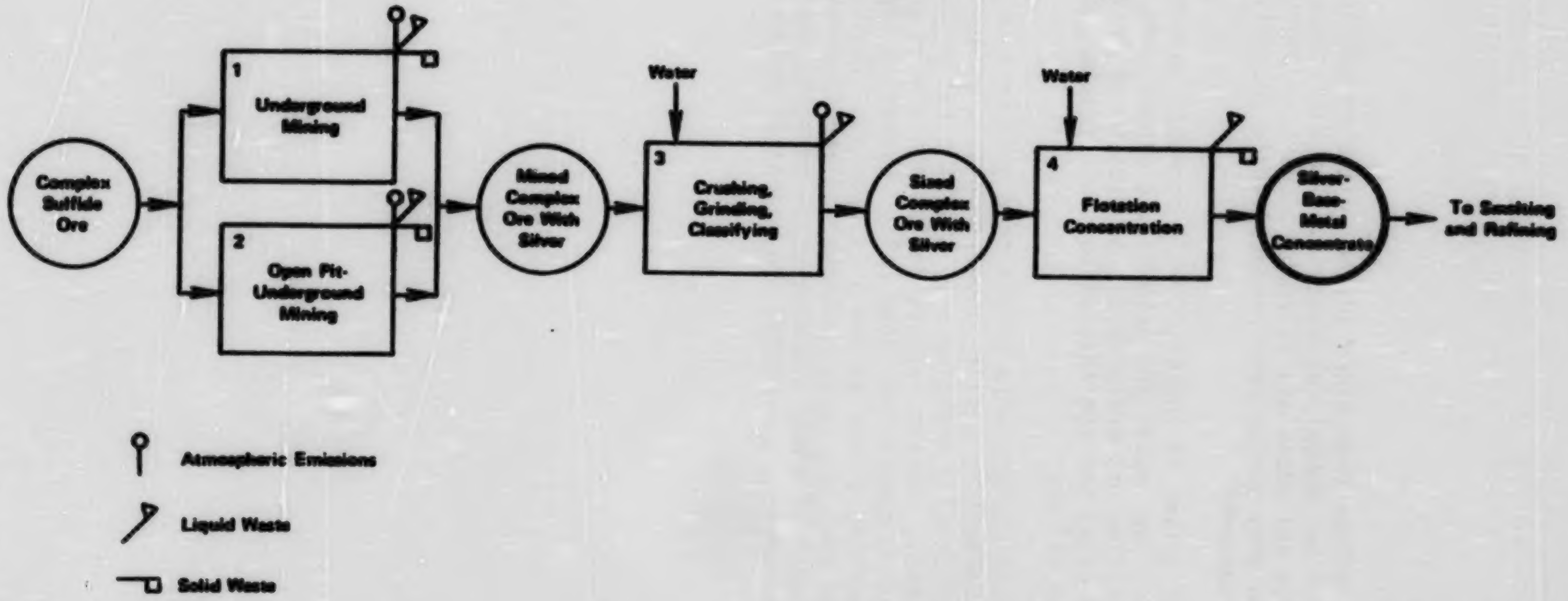
Silver

The production of silver from mines in the United States is less than one quarter of our annual consumption. The difference is supplied by imports and reclaimed silver from various sources. In 1973, 37.4 million troy ounces were produced while 185 million troy ounces were consumed

Mine production of silver is largely (~ 75 percent) byproduct silver from primary base metal and gold-silver mining. The balance is from ores classified primarily as silver ores which frequently contain more base metal per ton than silver but of lower total value per ton than silver.

Gold-silver ores can contain more silver than gold on a weight basis but silver content is usually lower than gold content in such ores. Placer gold usually contains only a little silver (commonly less than 10 percent). Recent reports indicate a single gold-silver mine producing more silver than gold. Currently there are no U.S. mines reporting silver as the only product. The U.S. reserves of silver ores are large, although silver concentrations are quite low in most of these deposits which prevents their exploitation under current economical and technical conditions.

Silver


Complex Sulfide Ore
1
Underground Mining
2
Open Pit-Underground Mining
Mined Complex Ore With Silver
Water
3
Crushing, Grinding, Classifying
Sized Complex Ore With Silver
Water
4
Flotation Concentration
Silver-Base-Metal Concentrate
To Smelting and Refining
Atmospheric Emissions
Liquid Waste
Solid Waste

SILVER - COMPLEX SULFIDE ORES PROCESS NO. 1

Underground Mining

1. Function - U.S. silver production is derived almost entirely from low-grade and complex primary sulfide ores. Three-fourths of this comes from ore in which lead, zinc, and copper constitute the principal values; one-fourth comes from ores where silver is the principal value in complex ore containing lead, zinc, and/or copper. Mining methods are similar to those used in mining several other metal ores.

   Underground mining involves the removal of ores from deep deposits by a number of techniques, the selection of which depends on the characteristics of the ore body. There are two main methods, caving and supported stoping. Caving methods used in the mining of ore containing silver include block caving used in large, homogeneous, structurally weak ore bodies, and top slicing for smaller and more irregular ore bodies. Supported stoping methods are used to mine veins and flat deposits of silver containing ore. There are two types, naturally supported and artifically supported. Natural support stoping methods include open stoping for small ore bodies and open stoping with natural pillar support for wider ore bodies, both of which have structurally strong foot walls (floors in bedded deposits) and hanging walls (roofs in bedded deposits). Artifically supported stoping methods include shrinkage stoping for steeply dipping tabular-shaped deposits having fairly strong foot and hanging walls, and little waste; cut and fill stoping for similarly shaped deposits having weak walls; and timbered or square-set stoping methods for cases where the ore is weak and the surrounding rock is so weak that temporary timbered support is necessary as an interim measure prior to filling with broken waste rocks.

2. Input Materials - Nitroglycerine explosives (dynamite). About 0.5 kg/metric ton (1 lb/short ton) of ore mined

3. Operating Parameters -

   Temperature: Ambient

   Pressure: Atmospheric

4. Utilities -

Electrical Energy: Amount used varies widely depending upon method of mining and type of ore body. Mean value estimated to be about 0.32 x 10^8 joules/metric ton (9 kWhe/metric ton or 0.086 x 10^6 Btu/short ton) of ore.

5. Waste Streams -

Mine water effluent

Storage of solid gangue

6. EPA Source Classification Code - None

7. References -

(1) U. S. Census of Mineral Industries, Major Group 10 (Copper, lead, zinc, gold, and silver ores) Table 3A, pp 10B-11; Table 7, pp 10-22.

(2) Private communication with members of the BCL staff who have conferred with producers.

(3) Development Document for Effluent Guidelines and Standards of Performance, Ore Mining and Dressing Industry (Draft), U. S. Environmental Protection Agency, Washington, D.C. (prepared by Calspan Corp., Buffalo, N. Y.), April 1975.

(4) Ryan, J. Patrick, Chapter on Silver, Mineral Facts and Problems, Bureau of Mines Bulletin 630, Bureau of Mines, U. S. Department of the Interior, Washington, D.C., 1965, pp 809-821.

(5) Ageton, Robert W., Chapter on Silver, Mineral Facts and Problems, Bureau of Mines Bulletin 650, Bureau of Mines, Department of the Interior, Washington, D.C., 1970, pp 723-737.

Open-Pit Mining

1. **Function** - U.S. silver production is derived almost entirely from low-grade and complex primary sulfide ores. Three-fourths of this comes from ore in which lead, zinc, and copper constitute the principal values; one-fourth comes from ores where silver is the principal value in complex ore containing lead, zinc, and/or copper. Mining methods are similar to those used in mining several other metal ores.

   Open-pit mining involves the removal of ore from deposits at or near the surface by a cycle of operations consisting of drilling blast holes, blasting the ore, loading the broken ore onto trucks or rail cars, and transporting it to the concentrators. (In a few cases, blasting is not required; ore is "ripped" by bulldozers and loaded.) Barren surface rock overlaying the deposit must be removed to uncover the ore body; such overburden may be up to (and, in one case, even exceeding)152 meters (500 feet) thick.

2. **Input Materials** - Explosives (ammonium nitrate-fuel oil) 0.55 Kg/metric ton (1.1/short ton) of material mined.

3. **Operating Parameters** -

   Temperature: Ambient

   Pressure: Atmospheric

4. **Utilities** -

   Typical Case -

   Electric Energy: 0.22 x 10^8 joules/metric ton (6.1 kWhe/metric ton or 0.058 x 10^6 Btu/short ton) of ore (0.7 percent silver, average).

   Natural Gas: 0.047 cu meter/metric ton (1.5 cu ft/short ton) of ore

   Diesel Fuels: 1.13 liters/metric ton (0.27 gal/short ton) of ore

5. Waste Streams -

Airborne particulates from blasting

Water run-off (including water used for dust control in various mining operations)

Storage of solid overburden wastes

6. EPA Source Classification Code - None exists

7. References -

(1) U. S. Census of Mineral Industries, Major Group 10 (Copper, lead, zonc, gold, and silver ores) Table 3A, pp 10B-11; Table 7, pp 10-22.

(2) Private communication with members of the BCL staff who have conferred with producers.

(3) Development Document for Effluent Guidelines and Standards of Performance, Ore Mining and Dressing Industry (Draft), U. S. Environmental Protection Agency, Washington, D.C. (prepared by Calspan Corp., Buffalo, N. Y.), April, 1975

(4) Ryan, J. Patrick, Chapter on Silver, Mineral Facts and Problems, Bureau of Mines Bulletin 630, Bureau of Mines, U. S. Department of the Interior, Washington, D.C., 1965, pp 809-821.

(5) Ageton, Robert W., Chapter on Silver, Mineral Facts and Problems, Bureau of Mines Bulletin 650, Bureau of Mines, Department of the Interior, Washington, D.C., 1970, pp 723-737.

Crushing, Grinding, and Classifying

1. Function - To prepare the mixed sulfide ores for flotation, the ore is crushed, then ground to a fineness sufficient to separate the valuable minerals from the gangue. A classifier is placed in circuit with the grinding mills to separate and return oversize particles for further grinding.

2. Input Materials - Ore, and water to the grinding circuits.

3. Operating Parameters - Crushing is a separate operation, usually done dry. Grinding is usually done wet in a closed circuit with a classifier.

   Temperature: Ambient

   Pressure: Atmospheric

4. Utilities -

   Crushing: 0.11 x 10^8 joules/metric ton (3.1 kWhe/metric ton or 0.029 x 10^6 Btu/short ton) of ore
   Grinding and Classifying: 0.56 x 10^8 joules/metric ton (15.4 kWhe/metric ton or o.15 x 10^6 Btu/short ton) of ore

5. Waste Streams -

   Dust, particulates from the crushing operation

   Water, effluents from grinding

   Waste rock (associated with crushing operation at mine shaft)

6. EPA Source Classification Code - None

7. References -

   (1) U.S. Census of Mineral Industries, Major Group 10 (Copper, lead, zinc, gold, and silver ores) Table 3A, pp 108-11; Table 7, pp 10-22.

(2) Private communication with members of the BCL staff who have conferred with producers.

(3) Development Document for Effluent Guidelines and Standards of Performance, Ore Mining and Dressing Industry (Draft), U. S. Environmental Protection Agency, Washington, D.C. (prepared by Calspan Corp., Buffalo, N. Y.), April 1975.

(4) Ryan, J. Patrick, Chapter on Silver, Mineral Facts and Problems, Bureau of Mines Bulletin 630, Bureau of Mines, U. S. Department of the Interior, Washington, D.C., 1965, pp 809-821.

(5) Ageton, Robert W., Chapter on Silver, Mineral Facts and Problems, Bureau of Mines Bulletin 650, Bureau of Mines, Department of the Interior, Washington, D.C., 1970, pp 723-737.

Flotation

1. Function - The flotation technique may be used to separate ground ore mineral particles from gangue mineral particles and from each other in complex ores if the differences in the surface characteristics between the various ore mineral and gangue particles are sufficiently large. In the flotation process, the ground ore is agitated by rising air bubbles in cells containing water, various oils, and chemical reagents which cause the mineral particle to be selectively wetted by the oil present and become attached to the rising air bubbles, whereupon they rise to the surface of the cell and are scraped off. In complex ores containing more than one ore mineral value, reagents called depressants are used to "depress" one type mineral particle while the other is being floated.

2. Input Materials - Ground ore, water, oils, inorganic, and organic flotation reagents.

3. Operating Parameters - Flotation cells are operated at ambient temperature and pressure.

4. Utilities -

   Electric Energy: 0.24×10^8 joules/metric ton (6.6 kWhe/metric ton or 0.063×10^6 Btu/short ton) of ground ore input

5. Waste Streams -

   Slurries containing tailings, reagent losses to tailings

   Solid Tailings remaining after dewatering

6. EPA Source Classification Code - None

7. References -

   (1) U.S. Census of Mineral Industries, Major Group 10 (Copper, lead, zinc, gold, and silver ores) Table 3A, pp 10B-11; Table 7, pp 10-22.

   (2) Private communication with members of the BCL staff who have conferred with producers.

(3) Development Document for Effluent Guidelines and Standards of Performance, Ore Mining and Dressing Industry (Draft) U. S. Environmental Protection Agency, Washington, D.C. (prepared by Calspan Corp., Buffalo, N. Y.), April 1975.

(4) Ryan, J. Patrick, Chapter on Silver, Mineral Facts and Problems, Bureau of Mines Bulletin 630, Bureau of Mines, U. S. Department of the Interior, Washington, D.C., 1965 pp 809-821.

(5) Ageton, Robert W., Chapter on Silver, Mineral Facts and Problems, Bureau of Mines Bulletin 650, Bureau of Mines, Department of the Interior, Washington, D.C., 1970, pp 723-737.

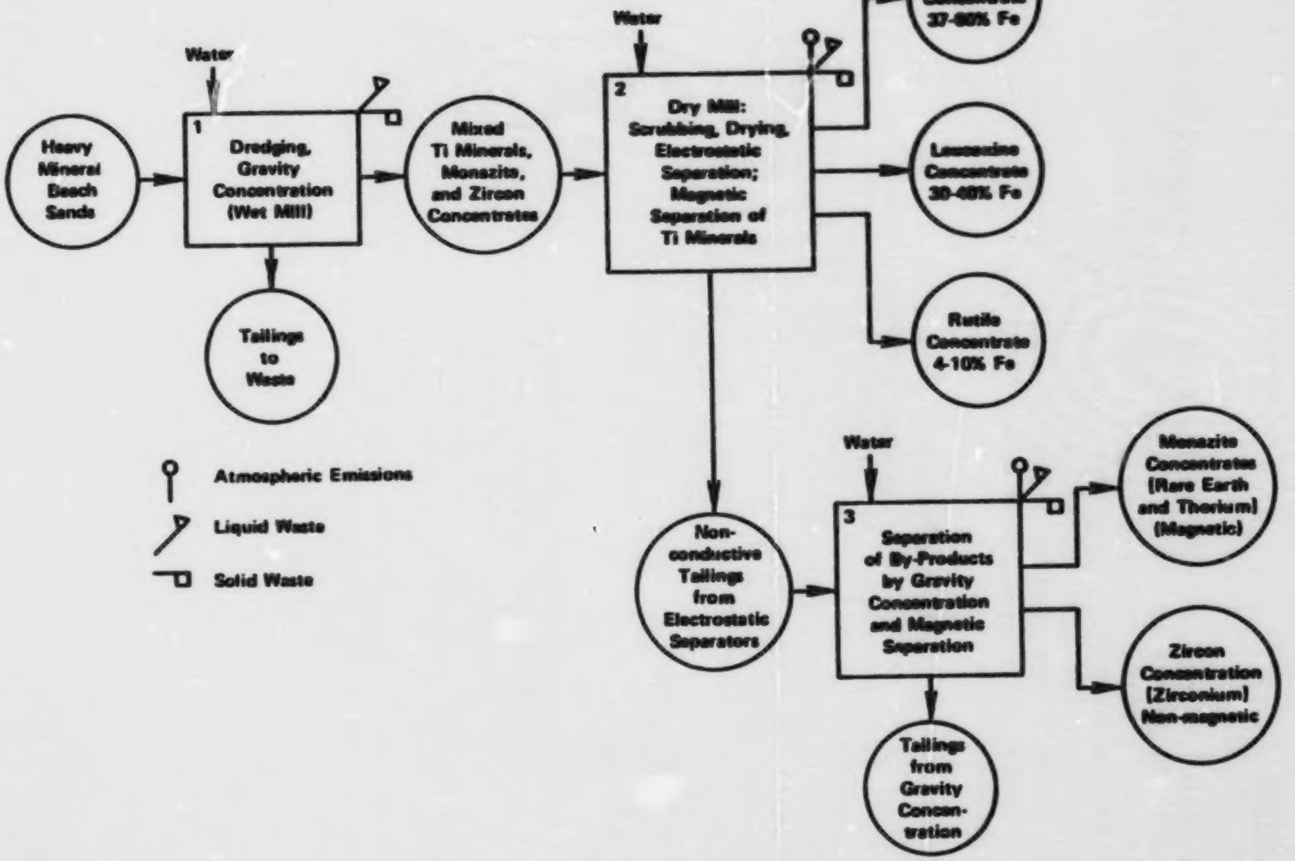
Titanium

The United States use of titanium metal has increased to about 35 million pounds in 1974. However, the use of metallic titanium is small compared to the far larger quantites of titanium oxide used in pigments, welding rods, etc. About 3 percent of the total titanium oxide utilized (881,000 tons in 1972) was used in producing metal. Approximately half of the oxide used is produced in domestic mines with the balance imported.

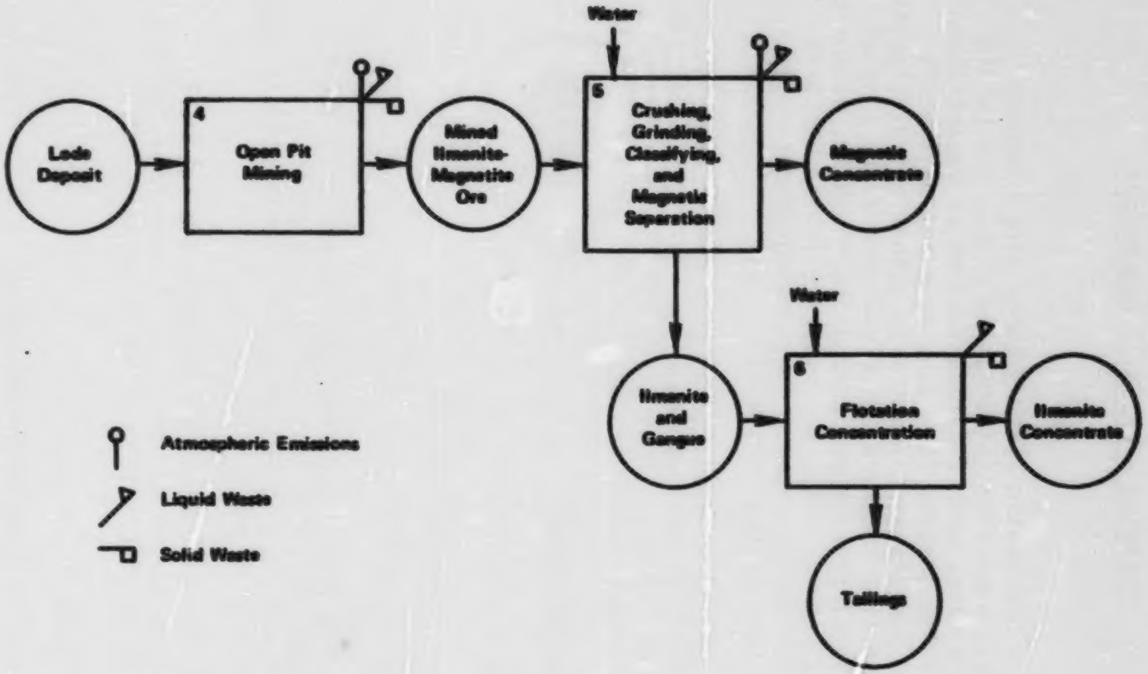
Lode deposits of titanium minerals are currently mined in Virginia (rutile and ilmenite together with nonmetallic minerals of value, e.g., aplite) and New York (ilmenite together with magnetite, an iron mineral) while placer titanium deposits are worked in New Jersey, Georgia, and Florida. The extensive placer deposits of heavy sands along the Eastern coast of the U.S. are fossil beach placers where the titanium mineralization is principally ilmenite with some rutile and leucoxene also present. In addition, these fossil beach placers contain zircon, $ZrSiO_4$, monazite, $(Ce, RE, Th)PO_4$, and other minerals which are usually recovered as by-products.

The fossil beach placer titanium deposits are float-dredged by creating a transient operating pond and the lode deposits are mined by open-pit methods. Beneficiation of the mined ores is accomplished by a variety of techniques ranging from simple gravity procedures to complicated circuits embodying gravity, electrostatic, flotation, and various-intensity magnetic separation methods. The methods used in the currently operating plants are outlined in the process flow diagram.

Titanium – Placer Deposits


Heavy Mineral Beach Sands
Water
1 Dredging, Gravity Concentration (Wet Mill)
Tailings to Waste
Mixed Ti Minerals, Monazite, and Zircon Concentrates
Water
2 Dry Mill: Scrubbing, Drying, Electrostatic Separation; Magnetic Separation of Ti Minerals
Ilmenite Concentrate 37-60% Fe
Leucoxene Concentrate 30-40% Fe
Rutile Concentrate 4-10% Fe
Non-conductive Tailings from Electrostatic Separators
Water
3 Separation of By-Products by Gravity Concentration and Magnetic Separation
Monazite Concentrates [Rare Earth and Thorium] (Magnetic)
Zircon Concentration [Zirconium] Non-magnetic
Tailings from Gravity Concen-tration
Atmospheric Emissions
Liquid Waste
Solid Waste

Titanium-Lode Deposits


Lode Deposit
4
Open Pit Mining
Mined Ilmenite-Magnetite Ore
Water
5
Crushing, Grinding, Classifying, and Magnetic Separation
Magnetic Concentrate
Ilmenite and Gangue
Water
6
Flotation Concentration
Ilmenite Concentrate
Tailings
Atmospheric Emissions
Liquid Waste
Solid Waste

Dredging - Wet Mill Operations

1. Function - Beach-sand placers containing ilmenite ($FeO \cdot TiO_2$), leucoxine (altered ilmenite), and rutile (TiO_2) are mined with floating suction or bucket-line dredges. The dredges feed sand to a wet mill where vibrating screens in circuit with either spiral classifiers or laminar flow roughers and cleaners produce a mixed heavy mineral concentrate containing ilmenite, leucoxine, rutile, zircon ($ZrSO_4$), and monazite (which contains rare earths and thorium). These mixed concentrates are then sent to the "dry mill".

2. Input Materials - "Heavy sand" from placer deposits and water. Sulfuric acid to reduce pH and aid flocculation of colloidal slime. Final discharge of clarified overflow neutralized with lime.

3. Operating Parameters -

   Temperature: Ambient

   Pressure: Atmospheric

4. Utilities -

   Electrical energy: for dredging and wet mill gravity concentration, 0.14×10^8 joules/metric ton (3.8 kWhe/metric ton or 0.037×10^6 Btu/short ton) of solids mined

   Fuel oil, diesel fuel: for dredging and wet mill gravity concentration, 0.54 liter/metric ton (0.13 gal/short ton) of solids mined

5. Waste Streams -

   Water used for gravity concentration is discharged to the dredge pond. No reagents are used in beneficiation. Sands contain organic materials which form a highly colored colloidal slime; high levels of phosphate and organic nitrogen also are present in the waste stream.

   Waste lubricating oil from the dredge and wet mill also goes to the dredge pond.

   Oversize from screens in circuit with classifiers goes to the dredge pond.

6. EPA Source Classification Code - None

7. References -

(1) Private communication with members of the BCL staff who have consulted with producers on energy requirements and specifics of operation.

(2) Development Document for Effluent Guidelines and Standards of Performance, Ore Mining and Dressing Industry (Draft), U. S. Environmental Protection Agency, Washington, D.C. (prepared by Calspan Corp., Buffalo, N. Y.), April 1975.

(3) Stamper, John W., Chapter on Titanium, Mineral Facts and Problems, 1965, Bureau of Mines Bulletin 630, U. S. Department of the Interior, Washington, D.C., pp 971-990.

(4) Stamper, John W., Chapter on Titanium, Mineral Facts and Problems, 1970, Bureau of Mines Bulletin 650, U. S. Department of the Interior, Washington, D.C., pp 773-794.

(5) Miller, Jesse A., Titanium, A Materials Survey, Bureau of Mines Information Circular 7791, U. S. Government Printing Office, Washington, D.C., 1957, 202 pp.

TITANIUM - HEAVY MINERAL BEACH SANDS

PROCESS NO. 2

Separation and Upgrading of Titanium Minerals in the "Dry" Mill

1. **Function** - Bulk concentrates from the wet mill are washed free of any remaining clay or adherent material in a scrubber plant, following which they are dried, and then electrostatically separated into conductive titanium mineral concentrates and non-conductive silicate (including zircon, $ZrSiO_4$) and monazite mineral concentrates. The titanium mineral concentrates undergo final separation in induced-roll magnetic separators; separation is based on their relative magnetic properties, which in turn is based on iron content: ilmenite has 37 to 65 percent iron, leucoxine has 30 to 40 percent iron, and rutile has 4 to 10 percent iron.

2. **Input Materials** - Bulk concentrate from the "wet mill" and water.

3. **Operating Parameters** -

   Temperature: (drying) 149-204 C (300-400 F)

   Pressure: Atmospheric

4. **Utilities** - Dry Mill; includes separation of by-product minerals:

   Electrical energy: 0.57 x 10^8 joules/metric ton (15.8 kWhe/metric ton or 0.15 x 10^6 Btu (short ton) of feed
   Fuel oil and diesel oil: 14.4 liters/metric ton (3.45 gals/short ton) of feed

5. **Waste Streams** -

   Dust, particulates in separation operations

   No water effluent from dry operations. Water effluent from scrubbing operations. Clay and other suspended solids from scrubbing operations. Tailings are disposed of in the next step--separation of by-product minerals.

6. EPA Source Classification Code - None

7. References -

(1) Private communication with members of the BCL staff who have consulted with producers on energy requirements and specifics of operation.

(2) Development Document for Effluent Guidelines and Standards of Performance, Ore Mining and Dressing Industry (Draft), U. S. Environmental Protection Agency, Washington, D.C. (prepared by Calspan Corp., Buffalo, N. Y.), April 1975.

(3) Stamper, John W., Chapter on Titanium, Mineral Facts and Problems, 1965, Bureau of Mines Bulletin 630, U. S. Department of the Interior, Washington, D.C., pp 971-990.

(4) Stamper, John W., Chapter on Titanium, Mineral Facts and Problems, 1970, Bureau of Mines Bulletin 650, U. S. Department of the Interior, Washington, D.C., pp 773-794.

(5) Miller, Jesse A., Titanium, A Materials Survey, Bureau of Mines Information Circular 7791, U. S. Government Printing Office, Washington, D.C., 1957, 202 pp.

Separation of By-Product Minerals in the Non-conductive Tailings from the Electrostatic Separators

1. Function - The non-conductive tailings from the high tension (HT) electrostatic separators may contain zircon ($ZrO_2 \cdot SiO_2$) and monazite (a rare earth phosphate mineral which, in turn, may contain thorium silicate in association with it).

In a typical operation, the tailings are first upgraded by either wet or dry gravity concentration (i.e., spirals or tables), following which they are separated from one another in induced-roll magnetic separators. Monazite, which is slightly magnetic, is separated from zircon, which is non-magnetic.

2. Input Materials - Tailings from the high-tension magnetic separators and water.

3. Operating Parameters -

Temperature: Ambient

Pressure: Atmospheric

4. Utilities (includes production of titanium minerals) -

Electrical energy: 0.57×10^8 joules/metric ton (15.8 kWhe/metric ton or 0.15×10^6 Btu/short ton) of feed
Fuel oil, diesel oil: 14.4 liters/metric ton (3.45 gals/short ton) of feed

5. Waste Streams -

Dust, particulates in dry separation operations

Water effluents from wet gravity concentration, where used

Tailings (may be either wet or dry, depending on the type of operation) from gravity concentration

6. EPA Source Classification Code - None

7. References -

(1) Private communication with members of the BCL staff who have consulted with producers on energy requirements and specifics of operation.

(2) Development Document for Effluent Guidelines and Standards of Performance, Ore Mining and Dressing Industry (Draft), U. S. Environmental Protection Agency, Washington, D.C. (prepared by Calspan Corp., Buffalo, N. Y.), April 1975.

(3) Stamper, John W., Chapter on Titanium, Mineral Facts and Problems, 1965, Bureau of Mines Bulletin 630, U. S. Department of the Interior, Washington, D.C., pp 971-990.

(4) Stamper, John W., Chapter on Titanium, Mineral Facts and Problems, 1970, Bureau of Mines Bulletin 650, U. S. Department of the Interior, Washington, D.C., pp 773-794.

(5) Miller, Jesse A., Titanium, A Materials Survey, Bureau of Mines Information Circular 7791, U. S. Government Printing Office, Washington, D.C., 1957, 202 pp.

TITANIUM - LODE DEPOSITS PROCESS NO. 4

Open Pit Mining

1. Function - The single lode deposit being exploited in the U. S. is a large ilmenite/magnetite deposit in the Lake Sanford area, Essex County, New York (one of four in the area). The ore body being exploited occurs as an outcrop on the side of Sanford Hill and is mined by conventional open pit methods. Approximately 1.1 metric tons (1.25 short tons) of waste rock must be removed to recover 0.91 metric ton (1.0 short ton of ore. The benches in this open pit mine are 10.7 meters (35 feet) high. Blast holes are placed so as to loosen 907 metric tons (1000 short tons) of rock. Some secondary breakage is required. Usually drop-ball cranes are used for this purpose, but some "mud-cap" secondary blasting is necessary. Loosened ore is trucked to the primary crushing operation.

2. Input Materials - Explosives, 6-8 metric tons of rock/kilogram (3-4 Short tons/lb) of explosive. Water impounded with tailing in an adjacent open-pit is recycled.

Operating Parameters -

Temperature: Ambient

Pressure: Atmospheric

4. Utilities (based on an analogous operation) -

Electrical energy: 0.99 x 10^8 joules/metric ton (27.6 kWhe/metric ton or 0.26 x 10^6 Btu/short ton) of ore

Diesel fuel: 0.71 liter/metric ton (0.17 gal/short ton) of ore

5. Waste Streams -

Airborne particulates from blasting and loading

Considerable amounts of water are discharged from the hillside pit, 2650 cu meters (700,000 gals) per day: It contains high concentrations of oils and greases, fluorides, Kjeldahl (organic) nitrogen, and nitrates (from nitrate-based explosives).

Solid waste is considerable, 1.25 times the amount of ore mined.

6. EPA Source Classification Code - None

7. References -

(1) Private communication with members of the BCL staff who have consulted with producers on energy requirements and specifics of operation.

(2) Development Document for Effluent Guidelines and Standards of Performance, Ore Mining and Dressing Industry (Draft), U. S. Environmental Protection Agency, Washington, D.C. (prepared by Calspan Corp., Buffalo, N. Y.), April 1975.

(3) Stamper, John W., Chapter on Titanium, Mineral Facts and Problems, 1965, Bureau of Mines Bulletin 630, U. S. Department of the Interior, Washington, D.C., pp 971-990.

(4) Stamper, John W., Chapter on Titanium, Mineral Facts and Problems, 1970, Bureau of Mines Bulletin 650, U. S. Department of the Interior, Washington, D.C., pp 773-794.

(5) Miller, Jesse A., Titanium, A Materials Survey, Bureau of Mines Information Circular 7791, U. S. Government Printing Office, Washington, D.C., 1957, 202 pp.

Magnetic Separation of Magnetite from Ilmenite and Gangue; Upgrading of Magnetite by Magnetic Processing

1. Function - Magnetite mineral particles are freed from ilmenite and gangue in ilmenite/magnetite ores by grinding and are separated by magnetic processing. The sequence of operations is as follows:

   Ores are initially crushed and screened. Both undersize and oversize are magnetically cobbed to remove nonmagnetic rock which is discarded. Oversize is further crushed, screened, and separated. Undersize is initially ground in rod mills in circuit with a classifier. Final grinding of the undersize from the classifier is done in a ball mill, after which the ground ore is magnetically separated into magnetite concentrate, and ilmenite mixed with gangue. The latter goes to the flotation machines. The magnetite concentrates are further upgraded by additional magnetic processing, following which they are dewatered and sent to storage to be followed by sintering to make a material suitable for blast furnace feed.

2. Input Materials - Mined ore, trucked from open pit mine and water.

3. Operating Parameters -

   Temperature: Ambient

   Pressure: Atmospheric

4. Utilities (based on analogous operation) -

   Electrical energy: for crushing, 0.11 x 10^8 joules/metric ton (3.1 kWhe/metric ton or 0.029 x 10^6 Btu/short ton) of feed, for grinding and classifying, 0.56 x 10^8 joules/metric ton (15.4 kWhe/metric ton or 0.15 x 10^6 Btu/short ton) of feed; for magnetic separation, 0.04 x 10^8 joules/metric ton (1.1 kWhe/metric ton or 0.011 x 10^6 Btu/short ton) of feed

5. Waste Streams -

   Dust, particulates from crushing operations

   Waste water from dewatering of magnetite concentrates

Tailings from the magnetic separators contain ilmenite and are sent on to the flotation machines.

6. EPA Source Classification Code - None

7. References -

(1) Private communication with members of the BCL staff who have consulted with producers on energy requirements and specifics of operation.

(2) Development Document for Effluent Guidelines and Standards of Performance, Ore Mining and Dressing Industry (Draft), U. S. Environmental Protection Agency, Washington, D.C. (prepared by Calspan Corp., Buffalo, N. Y.), April 1975.

(3) Stamper, John W., Chapter on Titanium, Mineral Facts and Problems, 1965, Bureau of Mines Bulletin 630, U. S. Department of the Interior, Washington, D.C., pp 971-990.

(4) Stamper, John W., Chapter on Titanium, Mineral Facts and Problems, 1970, Bureau of Mines Bulletin 650, U. S. Department of the Interior, Washington, D.C., pp 773-794.

(5) Miller, Jesse A., Titanium, A Materials Survey, Bureau of Mines Information Circular 7791, U. S. Government Printing Office, Washington, D.C., 1957, 202 pp.

TITANIUM - LODE DEPOSITS

PROCESS NO. 6

Separation of Ilmenite from Gangue by Flotation

1. **Function** - Non-magnetic ilmenite and gangue particles from the magnetic separators are upgraded in a flotation circuit consisting of roughers and three stages of cleaners. The floated ilmenite concentrate is then thickened, filtered, and dried prior to shipping.

2. **Input Materials** - Ground ilmenite and gangue from the magnetic separation operation and water. Flotation reagents in the following amounts:

Frothers

Tall oil	1.33 kg/metric ton (2.66 lb/short ton) of ore
Fuel oil	0.90 kg/metric ton (1.80 lb/short ton) of ore
Methyl amyl alcohol	0.080 kg/metric ton (0.16 lb/short ton) of ore

Depressant

Sodium bifluoride	0.76 kg/metric ton (1.52 lb/short ton) of ore

pH Modifier

Sulfuric acid	1.78 kg/metric ton (3.55 lb/short ton) of ore

3. **Operating Parameters** -

Temperature: Ambient

Pressure: Atmospheric

4. **Utilities** (based on analogous operation) -

Electrical energy, flotation: 0.24×10^8 joules/metric ton (6.6 kWhe/metric ton or 0.063×10^6 Btu/short ton) of feed

5. **Waste Streams** -

High amounts of suspended solids and relatively high levels of iron, titanium, zinc, nickel, vanadium, chromium, and selenium were found in the relatively voluminous waste streams from this mill [34,800 cu meter/day (9,200,000 gals/day)]. Flotation reagents listed in (2) Input Materials would also be present.

Solids - mineralogically, the ore averages 32 percent ilmenite, 37 percent magnetite, 16 percent feldspar, and 15 percent iron silicates. The latter two would be present in the slurry of finely ground tailings emanating from the mill.

6. EPA Source Classification Code - None

7. References -

(1) Private communication with members of the BCL staff who have consulted with producers on energy requirements and specifics of operation.

(2) Development Document for Effluent Guidelines and Standards of Performance, Ore Mining and Dressing Industry (Draft), U. S. Environmental Protection Agency, Washington, D.C. (prepared by Calspan Corp., Buffalo, N. Y.), April 1975.

(3) Stamper, John W., Chapter on Titanium, Mineral Facts and Problems, 1965, Bureau of Mines Bulletin 630, U. S. Department of the Interior, Washington, D.C., pp 971-990.

(4) Stamper, John W., Chapter on Titanium, Mineral Facts and Problems, 1970, Bureau of Mines Bulletin 650, U. S. Department of the Interior, Washington, D.C., pp 773-794.

(5) Miller, Jesse A., Titanium, A Materials Survey, Bureau of Mines Information Circular 7791, U. S. Government Printing Office, Washington, D.C., 1957, 202 pp.

Tungsten

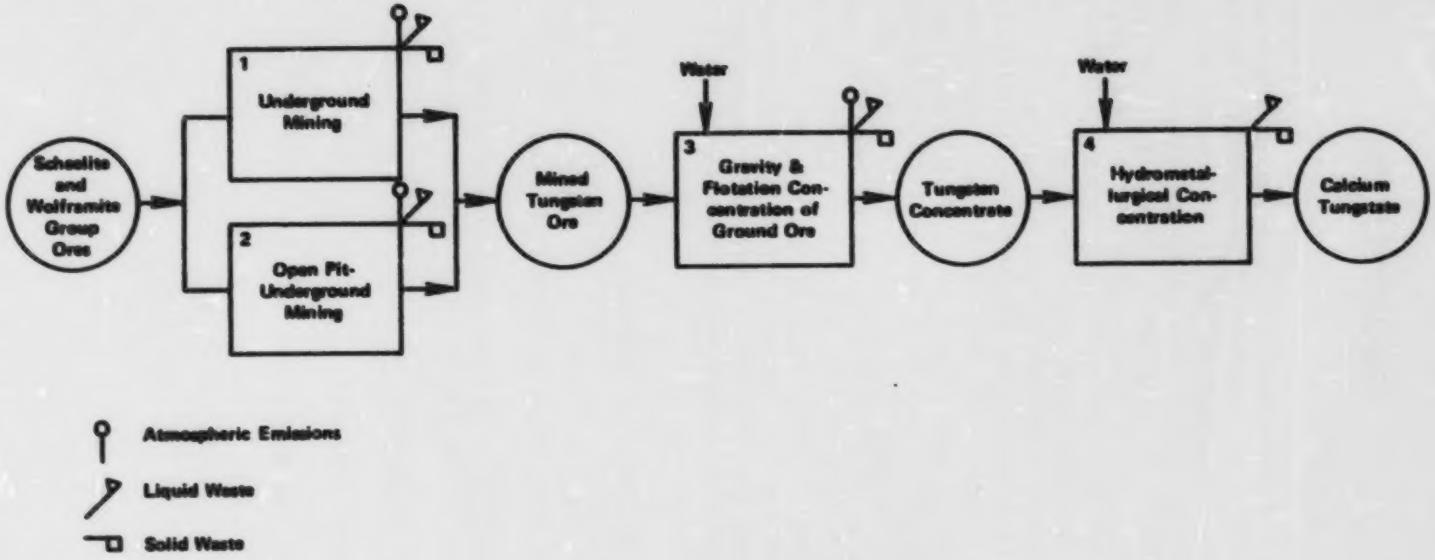
The tungsten mineral mining and beneficiating segment of the U.S. industry is not a large one, but it is important. Tungsten is one of the refractory metals that is of strategic importance in numerous and diverse applications (i.e., from light bulb filaments to tool bits, to the hard-facing of and alloying in other metals). Although our primary production of tungsten was formerly almost two-thirds of our demand (prior to 1950), current primary production of about 4 million pounds tungsten from domestic mines represents only about half of our demand for this metal. Much of the current production is as byproduct concentrate from the mining and beneficiating of ores for other metals (e.g., molybdenum) and presently all of the production is from our western states, principally California and Nevada (formerly some tungsten ores were recovered in North Carolina). Several of the mining operations are small-scale intermittently operating ventures which usually ship their ores to mills operated by the larger companies. There are apt to be no changes in this pattern for tungsten recovery since the tungsten ore reserves in the U.S. are of the high-cost (to process), low-grade type although there are considerable amounts of such deposits available.

Tactite is the rock type for the principal commercial source of tungsten in the United States. Tactites are the products of high-temperature replacement and recrystallization of pure or impure limestone or dolomite at or near the contact of intrusive igneous rocks. Where the mineralization includes tungsten, the tungsten content of the tactites occurs as scheelite, $CaWO_4$, often as molybdenum-containing scheelite, $Ca(W,Mo)O_4$; the former is the major tungsten mineral of the U.S.

Scheelite-bearing tactite deposits range in size from small isolated pods scattered along a contact to massive bodies which may contain many thousands of tons, although WO_3 contents of such large ore bodies is generally low. Some ores run up to 10 percent WO_3 in localized areas but overall, producing deposits average between 0.5 and 1 percent. Lower grade ore (about 0.3 percent WO_3) can be worked when tungsten prices are high.

The scheelite-containing tactite rock is dug, crushed and concentrated to produce a scheelite concentrate. Ideally a concentrate will contain about 60 percent WO_3. Lower WO_3 content concentrate can be enriched by an acid leaching process and chemical treatment wherein the ultimate product is ammonium paratungstate.

Tungsten


Scheelite and Wolframite Group Ores
1
Underground Mining
2
Open Pit-Underground Mining
Mined Tungsten Ore
Water
3
Gravity & Flotation Concentration of Ground Ore
Tungsten Concentrate
Water
4
Hydrometallurgical Concentration
Calcium Tungstate
Atmospheric Emissions
Liquid Waste
Solid Waste

Underground Mining

1. **Function** - Underground mining involves the removal of ores from deep deposits by a number of techniques, the selection of which depends on the characteristics of the ore body. There are two main methods, caving and supported stoping. Caving methods used in the mining of tungsten include block caving used in large, homogeneous, structurally weak ore bodies, and top-slicing for smaller and more irregular ore bodies. Supported stoping methods are used to mine veins and flat deposits of ore. There are two types, naturally supported and artificially supported. Natural support stoping methods include open stoping for small ore bodies and open stoping with natural pillar support for wider ore bodies, both of which have structurally strong foot walls (floors in bedded deposits) and hanging walls (roofs in bedded deposits). Artificially supported stoping methods include shrinkage stoping for steeply dipping tabular-shaped deposits having fairly strong foot and hanging walls, and little waste; cut-and-fill stoping for similarly shaped deposits having weak walls; and timbered or square-set stoping methods for cases where the ore is weak and the surrounding rock is so weak that temporary timbered support is necessary as an interim measure prior to filling with broken waste rock.

   Most of the tungsten produced in the U. S. is mined by underground methods. The largest producing mine, the Pine Creek Mine, in Inyo County, California, is mined by block caving methods. Most U. S. ore mined is scheelite ore.

2. **Input Materials** - Nitroglycerine explosives (dynamite): About 0.5 kg/metric ton (1 lb/short ton) of ore mined

3. **Operating Parameters** -

   Temperature: Ambient

   Pressure: Atmospheric

4. Utilities -

Electrical energy: Amount used varies widely depending upon method of mining and type of ore body. Mean value estimated to be about 0.32×10^8 joules/metric ton (9 kWhe/metric ton or 0.086×10^6 Btu/short ton) of ore.

5. Waste Streams -

Mine water effluent

Storage of solid gangue

6. EPA Source Classification Code - None

7. References -

(1) Private communication with members of the BCL staff who have consulted with producers on energy requirements and specifics of operation.

(2) Development Document for Effluent Guidelines and Standards of Performance, Ore Mining and Dressing Industry (Draft), U. S. Environmental Protection Agency, Washington, D.C. (prepared by the Calspan Corp., Buffalo, N. Y.), April 1975.

(3) Hallowell, J. B., et al., Water Pollution Control in the Primary Non-Ferrous Metals Industry, Vol II, Aluminum, Mercury, Gold, Silver, Molybdenum, and Tungsten, Office of Research and Development, U. S. Environmental Protection Agency, Washington, D.C., pp 75-113.

(4) U. S. Department of Commerce, Business and Defense Services Administration, Materials Survey, Tungsten, December 1956.

TUNGSTEN - SCHEELITE AND WOLFRAMITE GROUP ORES PROCESS NO. 2

Open Pit Mining

1. Function - Open pit mining involves the removal of ore from deposits at or near the surface by a cycle of operations consisting of drilling blast holes, blasting the ore, loading the broken ore onto trucks or rail cars, and transporting it to the concentrators. (In a few cases, blasting is not required; ore is "ripped" by bulldozers and loaded.) Barren surface rock overlaying the deposit must be removed to uncover the ore body.

   Underground systems are sometimes used to remove ore from an open pit. In such cases ore is mined and fed into a raise at the bottom of the pit, giving the pit a funnel shape which is referred to as a "gloryhole". The Round Valley Tungsten Mine at Bishop, California, uses this method.

2. Input Materials - Explosives (ammonium nitrate-fuel oil) 0.54 kg/metric ton (1.1/short ton) of material mined

3. Operating Parameters -

   Temperature: Ambient

   Pressure: Atmospheric

4. Utilities -

   Typical Case -

   Electrical energy: 0.22 x 10^8 joules/metric ton (6.1 kWhe/metric ton or 0.058 x 10^6 Btu/short ton) of ore
   Natural gas: 0.047 cu meter/metric ton (1.5 cu ft/short ton) of ore
   Diesel fuels: 1.13 liters/metric ton (0.27 gal/short ton) of ore

5. Waste Streams -

   Airborne particulates from blasting

Water runoff (including water used for dust control in various mining operations)

Storage of solid overburden wastes

6. EPA Source Classification Code - None

7. References -

(1) Private communication with members of the BCL staff who have consulted with producers on energy requirements and specifics of operation.

(2) Development Document for Effluent Guidelines and Standards of Performance, Ore Mining and Dressing Industry (Draft), U. S. Environmental Protection Agency, Washington, D.C. (prepared by the Calspan Corp., Buffalo, N. Y.), April 1975.

(3) Hallowell, J. B., et al., Water Pollution Control in the Primary Non-Ferrous Metals Industry, Vol II, Aluminum, Mercury, Gold, Silver, Molybdenum, and Tungsten, Office of Research and Development, U. S. Environmental Protection Agency, Washington, D.C., pp 75-113.

(4) U. S. Department of Commerce, Business and Defense Services Administration, Materials Survey, Tungsten, December 1956.

Gravity and Flotation Concentration

1. Function - The specific gravity of tungsten minerals is high and therefore gravity concentration methods are used primarily. However, scheelite, the principal U. S. ore, is very friable and in the process of wet-grinding a considerable amount of slimes are produced which reduce recovery by gravity techniques. To increase overall recovery, the finely divided scheelite particles in the slimes are concentrated by flotation techniques using fatty acids as collectors.

   Molybdenum and copper sulfide minerals are frequently associated by-product minerals in the ore. After crushing and wet-grinding, these are removed from the ore (and each other, subsequently) by flotation methods, using xanthates as collectors and soda ash for pH modification. Tailings from this operation are refloated using tail oil soap as collectors to recover the scheelite.

   U. S. tungsten ores have an average concentration of 0.6% tungsten. There is no typical single procedure because the ores are complex and usually require the recovery of co-products or by-products. The concentration processes all involve the liberation steps of crushing, grinding, and classifying. Grinding is usually done either in rod mills or a combination of rod and ball mills to avoid excessive production of fines. Following grinding and classifying, subsequent processing depends on the type of ore being processed; frequently only the slimes are processed by flotation, the coarser material being concentrated by gravity techniques. As noted above, when by-products are present, a combination of sulfide flotation and scheelite flotation is used. This is usually followed by further gravity concentration of the scheelite concentrate.

   The magnetic separation of wolframite, $(Fe,Mn)WO_4$, concentrates and cassiterite, SnO_2, concentrates as by-products from a Colorado molybdenum ore is covered under Molybdenum - Ores Containing MoS_2 - Process No. 5, By-Product Recovery.

2. Input Materials - Mined tungsten ores, ores containing tungsten as a by-product, flotation reagents (proprietary collectors and frothers), soda ash and caustic soda for pH control, sodium silicate (depressant for silicates), and sodium cyanide (depressant for sulfides), fattv acids, xanthates and water.

3. Operating Parameters - Flotation of scheelite is difficult as compared to metal sulfide flotation. Density of the incoming pulp is critical and in a typical operation is maintained at 35 percent solids. Temperature minimum is around 16 C (60 F). The pH of the pulp is maintained between 10 and 10.2.

4. Utilities -

Electrical energy; for crushing, 0.11 x 10^8 joules/metric ton or 0.029 x 10^6 Btu/short ton) of ore; for grinding, 0.56 x 10^8 joules/metric ton (15.4 kWhe/metric ton or 0.15 x 10^6 Btu/short ton) of ore; for gravity concentration and flotation, 0.41 x 10^8 joules/metric ton (11/4 kWhe/metric ton or 0.11 x 10^6 But/short ton) of ore.

5. Waste Streams -

Dust, particulates from crushing operation

Tailings from gravity and flotation concentration. Flotation reagents

Concentrates are leached in the next beneficiation step. See Tungsten - Scheelite and Wolframite Group Ores - Process No. 4, Hydrometallurgical Concentration.

Suspended and dissolved solids in tailing slurry.

Voluminous solids, values in ore in the order of 1 percent.

6. EPA Source Classification Code - None

7. References -

(1) Private communication with members of the BCL staff who have consulted with producers on energy requirements and specifics of operation.

(2) Development Document for Effluent Guidelines and Standards of Performance, Ore Mining and Dressing Industry (Draft), U. S. Environmental Protection Agency, Washington, D.C. (prepared by the Calspan Corp., Buffalo, N. Y.), April 1975.

(3) Hallowell, J. B., et al., Water Pollution Control in the Primary Non-Ferrous Metals Industry, Vol II, Aluminum, Mercury, Gold, Silver, Molybdenum, and Tungsten, Office of Research and Development, U. S. Environmental Protection Agency, Washington, D.C., pp 75-113.

(4) U. S. Department of Commerce, Business and Defense Services Administration, Materials Survey, Tungsten, December 1956.

Hydrometallurgical Concentration

1. Function - There are many variations in hydrometallurgical procedures for upgrading tungsten concentrates practiced in the U.S. Differences in the deposits require different procedures.

Scheelite concentrates from the flotation machines tend to be low grade as compared with gravity concentrates. Calcite (calcium carbonate) and apatite (calcium fluorophosphate) are the principal contaminants in these low-grade concentrates (scheelite concentrates seldom contain sulfides in large amounts). These impurities may be leached out with acid, and the concentrates upgraded in the process. A first-stage leach with hydrochloric acid (HCl) removes the calcite as calcium chloride ($CaCl_2$) solution, which is discarded. A second-stage leach is used to dissolve the apatite [$CaF(PO_4)_3$], which is not dissolved in the presence of calcium chloride.

The iron and manganese in the wolframite series of minerals require a pressurized alkaline treatment of concentrates to produce sodium tungstate in solution with minimum leaching of the other constituents. Additions of hydrochloric acid to the leach solution causes the precipitation of solid tungstic acid (H_3WO_4). Heating to 1000 C (1830 F) decomposes the acid to tungsten trioxide.

Usually, separation from by-products such as molybdenum, as well as treatment of slimes not amenable to concentration by physical means, necessitates the pressured alkali treatment for both types of ores to form a synthetic scheelite.

One of the many variations of tungsten ore beneficiation procedures is the hydrometallurgical treatment of low-grade scheelite group concentrates to produce calcium tungstate. A water slurry of scheelite concentrates from the flotation machines are digested in a pressurized digester vessel with sodium carbonate and steam to produce tungstate and molybdate in solution. To remove the molybdenum, the solution is filtered and heated to 91 C (195 F), and sodium sulfide is added to precipitate molybdenum. The pH is adjusted to 3.0 with H_2SO_4 to complete this separation. Following this, the hot purified solution is neutralized with sodium hydroxide to a 9.2 pH, then treated with calcium chloride to precipitate calcium tungstate. Alternatively, the filtered solution after molybdenum separation may be solvent-extracted by a proprietary process to produce ammonium paratungstate, which is crystallized out of solution and dried.

2. Input Materials - Tungsten concentrates from the flotation operation. Hydrochloric acid for leaching out apatite and calcite from scheelite concentrates. Sodium carbonate and sodium sulfide in procedures which require digestion with alkali hydroxides and removal of molybdenum as a sulfide precipitate, and water.

3. Operating Parameters -

In leaching scheelite with hydrochloric acid to remove calcite and apatite, the pulp in wood-stave leach tanks contains about 60 percent solids. In the first stage of leaching, HCl is added until the liberation of CO_2 is complete. This occurs at a pH of 2.5 - 3.0. This liquor is decanted off the settled solids, and the concentrates are given a second leach at 91 C (195 F) in HCl in sufficient amounts to bring the phosphorus content of a washed sample of concentrates to 0.03%.

In the pressured alkaline treatment, a slurry of tungsten concentrates is passed through a bank of pressure vessels in a continuous flow. Steam is introduced in the amounts necessary to achieve a reacting temperature of 188 C (370 F) at a pressure of 13.6 atmospheres (200 psi).

4. Utilities -

Electrical energy: 2.4×10^8 joules/metric ton (66 kWhe/metric ton or 0.63×10^6 Btu/short ton) of $CaWO_4$
Natural gas: 231 cu meters/metric ton (7400 cu ft/short ton) of $CaWO_4$

5. Waste Streams -

Acid leach residues in plants using an HCl acid leach to upgrade flotation concentrates. High calcium and phosphorus contents.

Alkaline effluents (pH 10) in plants using pressurized alkaline digestion; these contain high concentrations of manganese and molybdenum.

Ammonia in plants producing ammonium paratungstate.

6. EPA Source Classification Code - None

7. References -

(1) Private communication with members of the BCL staff who have consulted with producers on energy requirements and specifics of operation.

(2) Development Document for Effluent Guideline and Standards of Performance, Ore Mining and Dressing Industry (Draft), U. S. Environmental Protection Agency, Washington, D.C. (prepared by the Calspan Corp., Buffalo, N. Y.), April 1975.

(3) Hallowell, J. B., et al., Water Pollution Control in the Primary Non-Ferrous Metals Industry, Vol II, Aluminum, Mercury, Gold, Silver, Molybdenum, and Tungsten, Office of Research and Development, U. S. Environmental Protection Agency, Washington, D.C., pp 75-113.

(4) U. S. Department of Commerce, Business and Defense Services Administration, Materials Survey, Tungsten, December 1956.

Uranium

In the United States, large exploitable deposits of uranium are found chiefly in sandstone and associated rocks. The geographical distribution of exploitable deposits is in the Western States. Production leaders are New Mexico, Wyoming, Colorado, and Utah in that order. Some uranium also is taken from Alaska, Washington, Texas, and as a minor byproduct from some Arizona copper deposits.

The domestic production of about 7 million tons of ore was reported for 1973. These ores averaged 0.213 percent U_3O_8. Mills recovered close to 14,000 tons, U_3O_8. Almost 2,300 tons of concentrate were imported. The market is one of oversupply. However, the longer range view is not so optimistic. Projected uranium demands would exhaust the domestic reserves in approximately 50 years.

(Radium)

> The United States was the major world producer of radium from the Colorado Plateau carnotite deposits until in the 1920's when the high-grade pitchblend (uraninite) deposits of the former Belgium Congo were exploited.
>
> Currently, the uranium content of U.S. ores is recovered while the radium content is dumped. Radium is only slightly soluble in the leaching processes used for the recovery of uranium and remains in the waste products. Such waste must be handled properly to prevent contamination of streams and underground waters. The Bureau of Mines has conducted investigations of the problem in several mills. The best methods to date, consist of recycling of the raffinate*, providing for soil seepage, and treating the solution with a barium salt which tends to precipitate and immobilize the radium. The problem has not yet been solved satisfactorily.

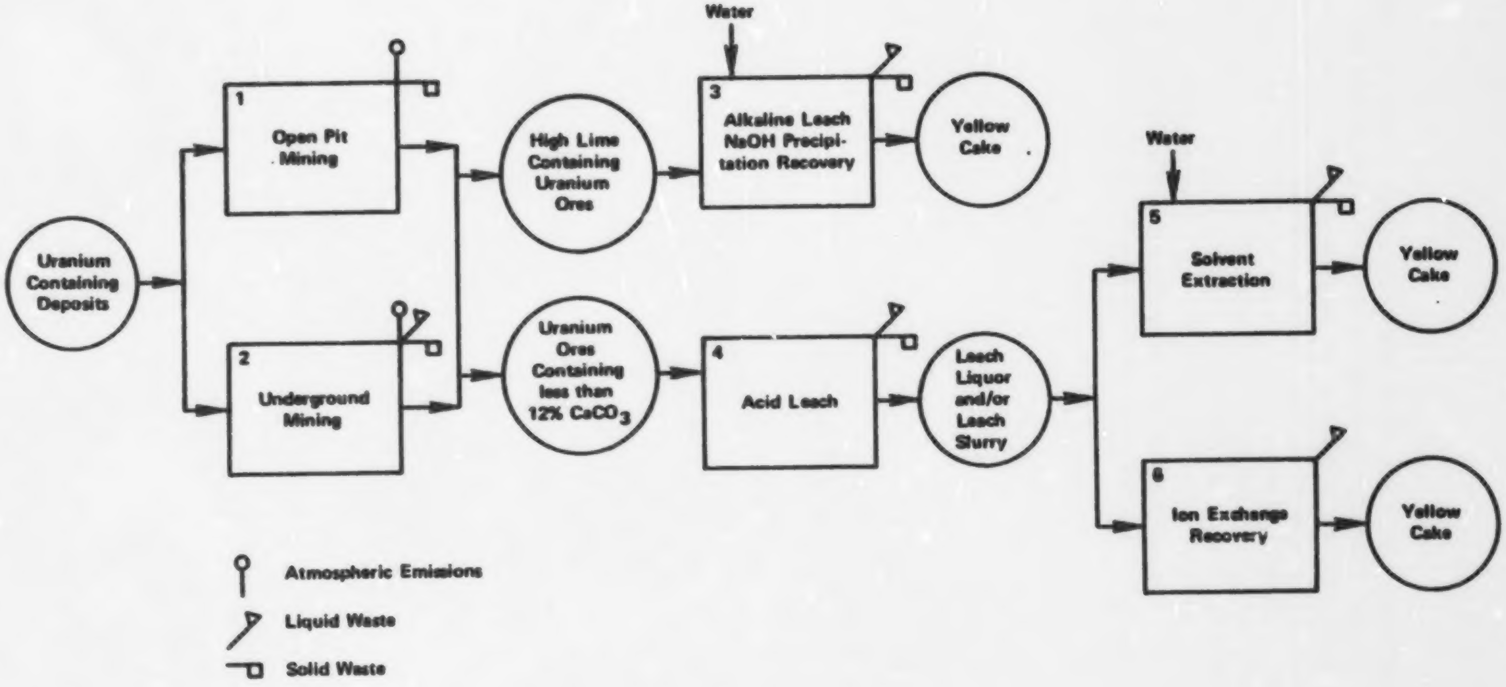
In view of the complexities of the mineralization in deposits mined for their uranium content, the terminology of the raw material sufficient for description in this report is--uranium content deposit. It will be understood that this term may be used to include additional value minerals such as those of molybdenum, thorium and vanadium that may occasionally occur in a few deposits.

---

*Raffinate. Waste liquors from ion exchange or solvent extraction processes.

Uranium processing utilizes more chemical than physical methods. In fact, many ore processing techniques are almost wholly chemical and are accomplished at plants that may be remote from mining sites. A single plant might service the output from a number of mines on a toll basis. Nevertheless, such plants and their product is "Yellow Cake", which is composed of one of several insoluble uranium compounds precipitated from a penultimate uranium salt in solution. The yellow cake may be a sodium, magnesium, or an ammonium salt. The concentrates vary from 70 to 80 percent in their U_3O_8 (equivalent) content and contain about 1 percent of moisture.

Uranium


Uranium Containing Deposits
1
Open Pit Mining
2
Underground Mining
High Lime Containing Uranium Ores
Uranium Ores Containing less than 12% $CaCO_3$
Water
3
Alkaline Leach NaOH Precipitation Recovery
Yellow Cake
4
Acid Leach
Leach Liquor and/or Leach Slurry
Water
5
Solvent Extraction
Yellow Cake
6
Ion Exchange Recovery
Yellow Cake
Atmospheric Emissions
Liquid Waste
Solid Waste

Open Pit Mining

1. Function - Open-pit mines accounted for 63 percent of uranium mined in the U.S. in 1973. Open-pit mining involves the removal of ore from deposits at or near the surface by a cycle of operations consisting of drilling blast holes, blasting the ore, loading the broken ore onto trucks or rail cars, and transporting it to the concentrators. (In a few cases, blasting is not required; ore is "ripped" by bulldozers and loaded.) Barren surface rock overlaying the deposit must be removed to uncover the ore body.

   Present practice is to stock-pile low-grade ores for future use. Average uranium content of the ore is 0.2 percent uranium oxide, U_3O_8, i.e., $UO_22(UO_3)$.

2. Input Materials - Explosives (ammonium nitrate-fuel oil) 0.55 kg/metric ton (1.1 lb/short ton) of ore

3. Operating Parameters -

   Temperature: Ambient

   Pressure: Atmospheric

4. Utilities -

   Electric Energy: 0.63×10^8 joules/metric ton (17.4 kWhe/metric ton or 0.17×10^6 Btu/short ton) of ore
   Fuel Oil: 12.6 liters/metric ton (3.0 gals/short ton) of ore

   (NOTE: The amount of energy used per ton of ore in open-pit uranium ore mining is higher than that in the mining of copper ore by open-pit methods. Both reported rates of use reflect producer's figures.)

5. Waste Streams -

   Dust, particulates in blasting and loading

The large U.S. deposits of uranium are in arid areas in the western United States.

Open-pit mines in this area lose more water by evaporation than they gain by seepage from aquifiers.

Radioactive nuclides are present in wastes from the mining operations. Further details on this aspect of mining uranium ores is covered in the next section, underground mining of uranium ores.

6. EPA Source Classification Code - None

7. References -

(1) Private communication with members of the BCL staff who have consulted with producers on energy requirements and specifics of operation.

(2) Development Document for Effluent Guidelines and Standards of Performance, Ore Mining and Dressing Industry (Draft), U. S. Environmental Protection Agency, Washington, D.C. (prepared by Calspan Corp., Buffalo, N. Y.), April, 1975.

(3) DeCurlo, Joseph A., and Shortt, Charles E., Chapter on Uranium, Mineral Facts and Problems, 1970, Bureau of Mines Bulletin 650, Bureau of Mines, U. S. Department of the Interior, Washington, D.C., pp 219-242.

(4) Baroch, Charles T., Chapter on Uranium, Mineral Facts and Problem, 1965, Bureau of Mines Bulletin 630, Bureau of Mines, U. S. Department of the Interior, Washington, D.C., pp 1007-1035.

Underground Mining

1. Function - Mining methods in the larger uranium ore deposits include room and pillar, longwall retreat, and panel methods. Modification of each are common and some features of each may be found in all of these methods. Underground mines accounted for 36 percent of uranium mined in the U.S. in 1973.

2. Input Materials - Explosives (Based on analogous underground mining operation) About 0.5 kg/metric ton (1.0 lb/short ton) of ore

3. Operating Parameters -

   Temperature: Ambient

   Pressure: Atmospheric

4. Utilities - (Based on analogous operations)

   Electric Energy: About 1.8 x 10^8 joules/metric ton (50 kWhe/metric ton or 0.47 x 10^6 Btu/short ton) of ore

5. Waste Streams -

   Radon gas and mine dusts present radiation hazards. Radon is a gaseous decay product of radium. Therefore, special ventilation procedures are necessary in uranium underground mines.

   As mentioned in the preceding section on open-pit mining, uranium mining is conducted primarily in arid areas. Relatively few mines discharge any water. Where it is practical, mine waste water is used as process feed water for milling. Also, where dry mines are near the mines discharging waste water, the discharge is often recycled to the dry mines for in situ leaching.

   Decay products present in the uranium ores include isotopes of uranium, thorium, and radium. Therefore, build-up of these decay products in the recycle operation accompanying ion-exchange recovery of values from these leach solutions is inevitable. Accordingly, high fractions of these decay products particularly that of the most toxic isotope, radium 226, are present in raw wastes from these mines.

Organics derived from carbonaceous ores are also present in raw waste water from mines. Total dissolved solids in waste waters may be high. Effluents may contain appreciable concentrations of calcium and magnesium, uranium, and iron.

A considerable fraction of radium 226 remains in the tailing after beneficiation. The uranium content may also be too high for safe release to the environment.

6. EPA Source Classification Code - None

7. References -

(1) Private communication with members of the BCL staff who have consulted with producers on energy requirements and specifics of operation.

(2) Development Document for Effluent Guidelines and Standards of Performance, Ore Mining and Dressing Industry (Draft), U. S. Environmental Protection Agency, Washington, D.C. (prepared by Calspan Corp., Buffalo, N. Y.), April 1975.

(3) DeCurlo, Joseph A., and Shortt, Charles E., Chapter on Uranium, Mineral Facts and Problems, 1970, Bureau of Mines Bulletin 650, Bureau of Mines, U. S. Department of the Interior, Washington, D.C., pp 219-242.

(4) Baroch, Charles T., Chapter on Uranium, Mineral Facts and Problems, 1965, Bureau of Mines Bulletin 630, Bureau of Mines, U. S. Department of the Interior, Washington, D.C., pp 1007-1035.

Recovery of Uranium from High Lime Ores by Alkaline Leaching and Direct Precipitation with Caustic Soda

1. Function - Solutions of sodium carbonate (40-50 g/l) in an oxidizing environment are used to leach uranium and vanadium values from high lime content ores. Alkaline leaching is slower than acid leaching. It, therefore, is used at higher temperatures (80-100 C; 175-212 F) and pressures. Leaching may take place under hydrostatic pressure at the bottom of a pachuca tank with oxygen being supplied by air agitation; air from a compressor is introduced at the bottom of the tank. Alternatively the leach tank may be pressured with oxygen. Potassium permanganate is sometimes added to the leach when additional oxidant is required.

The alkaline leach does not react with gangue minerals, therefore, the ore must be finely ground (to 200 mesh, 700 micrometers) to obtain exposure of the uranium minerals to the leach.

Leach liquors are separated from residues by countercurrent decantation, thickening, and pressurized filtration. The leach solution is regenerated by recarbonization with sodium bicarbonate additions. Sometimes the residues (tails and slimes) are given a scavenging leach to improve efficiency. After filtration, uranium is precipitated from solution. The usual method is to add caustic soda to the solution to raise the pH and precipitate the uranium as sodium diuranate, after which it is filtered, washed, dried, and packaged in drums as "yellow cake".

If vanadium is present in alkaline leached ore, the clarified liquor is neutralized after clarification and filtration with acid to a pH of 6, causing uranylvanadate to precipitate. It is recovered by thickening and filtering. The precipitate is then roasted with soda ash and carbon to reduce uranium to insoluble UO_2. The soluble sodium vanadate in the roasted mixture is separated by water leaching leaving a "yellow cake" residuum which is a marketable uranium end product.

There are three mills using the alkaline leach process in the United States; two of them use the caustic soda precipitation method described here; one uses a resin-in-pulp ion-exchange method described under Process No. 6.

2. Input Materials - Filtered uranium-bearing solution; sodium carbonate 40-50 g/l; air or oxygen for oxidation; and sodium bicarbonate, 10-20 g/l (in the regeneration of leach solution by exposure to carbon dioxide via the recarbonation); water.

3. Operating Parameters -

Temperature: 80-100 C (176-212 F)

Pressure: Hydrostatic pressure prevailing at the bottom of a 15 to 20 M (50-65 ft) cylindrical tank agitated by a cental airlift.

Duration of Leach: About 2 days

4. Utilities -

Electric Energy: for crushing and screening, 0.14 x 10^8 joules/metric ton (4.0 kWhe/metric ton or 0.038 x 10^6 Btu/short ton) of ore; for wet grinding, 0.75 x 10^8 joules/metric ton (21 kWhe/metric ton or 0.20 x 10^6 Btu/short ton) of ore; for classification, 0.07 x 10^8 joules/metric ton (2.0 kWhe/metric ton or 0.019 x 10^6 Btu/short ton) of ore; for pressurized leaching, 0.11 x 10^8 joules/metric ton (3.0 kWhe/metric ton or 0.028 x 10^6 Btu/short ton) of ore; for filtration, 0.14 x 10^8 joules/metric ton (4.0 kWhe/metric ton or 0.038 x 10^6 Btu/short ton) of ore; for precipitation, 0.10 x 10^8 joules/metric ton (2.9 kWhe/metric ton or 0.027 x 10^6 Btu/short ton) of ore; for filtration, 0.07 x 10^8 joules/metric ton (2.0 kWhe/metric ton or 0.019 x 10^6 Btu/short ton) of ore; for drying, 0.07 x 10^8 joules/metric ton (2.0 kWhe/metric ton or 0.019 x 10^6 Btu/short ton) of ore.

Natural Gas: for crushing and screening, 1.31 cu meters/metric ton (42 cu ft/short ton) of ore; for wet grinding, 1.64 cu meters/metric ton (52.6 cu ft/short ton) of ore; for classification, 0.66 cu meters/metric ton (21 cu ft/short ton) of ore; for pressurized leaching, 13.1 cu meters/metric ton (420 cu ft/short ton) of ore; for filtration, 1.0 cu meter/metric ton (31.6 cu ft/short ton) of ore; for drying, 8.55 cu meter/metric ton (274 cu ft/short ton) of ore

5. Waste Streams -

Stack gas from recarbonation treatment

Leach is recycled via the recarbonation loop

Alkaline leach mills discharge sodium carbonate

Waste water from sodium removal purification step

Repulped tailings to pond

A considerable fraction of radium 226 remains in the tailings. Also the uranium content may be too high for safe release to the environment.

6. EPA Source Classification Code - None

7. References -

(1) Private communication with members of the BCL staff who have consulted with producers on energy requirements and specifics of operation.

(2) Development Document for Effluent Guidelines and Standards of Performance, Ore Mining and Dressing Industry (Draft), U. S. Environmental Protection Agency, Washington, D.C. (prepared by Calspan Corp., Buffalo, N.Y.), April 1975.

(3) DeCurlo, Joseph A., and Shortt, Charles E., Chapter on Uranium, Mineral Facts and Problems, 1970, Bureau of Mines Bulletin 650, Bureau of Mines, U. S. Department of the Interior, Washington, D.C., pp 219-242.

(4) Baroch, Charles T., Chapter on Uranium, Mineral Facts and Problems, 1965, Bureau of Mines Bulletin 630, Bureau of Mines, U. S. Department of the Interior, Washington, D.C., pp 1007-1035.

Acid Leaching of Uranium Ores

1. Function - Uranium ores containing less than 12 percent calcium carbonate are acid leached.

   Ores are blended, crushed, and ground to 0.6 mm (28 mesh) in preparation for acid leaching. Some ores require an intermediate roast either to burn out organic material or improve filtering characteristics (in the case of clayey ores), or to solubilize associated vanadium compounds (in the case of chloride roasting of high vanadium content ores to convert the vanadium to water-soluble sodium orthovanadate, Na_3VO_4, so that vanadium maybe removed by water leaching prior to the acid leaching step).

   In the acid leaching operation, the ground ore is leached with sulfuric acid either in mechanically agitated tanks or in air-agitated columns. Oxidizers such as sodium chlorate, $NaClO_3$, or manganese dioxide are added to the leaching solution to oxidize any tetravalent uranium to the hexavalent state. The resultant leach solution slurry is classified into sand and slime fractions in hydrocyclones, thickened, and filtered to produce a clear pregnant liquor required for subsequent uranium recovery.

2. Input Materials - Ground ore, 0.6 mm (28 mesh); oxidizer, sodium chlorate 2 kg/metric ton (4 lbs/short ton) of ore; sulfuric acid, 26 kg/metric ton (52 lbs/short ton) of ore

3. Operating Parameters - Ores are leached at slightly above room temperatures. With agitation, leaching is completed in less than 8 hours. The agitated tanks and columns operate at atmospheric pressure.

4. Utilities -

   Electric Energy: for crushing and screening, 0.15×10^8 joules/metric ton (4.2 kWhe/metric ton or 0.040×10^6 Btu/short ton) of ore; for wet grinding, 0.20×10^8 joules/metric ton (5.6 kWhe/metric ton or 0.054×10^6 Btu/short ton) of ore; for digestion, 0.10×10^8 joules/metric ton (2.8 kWhe/metric ton or 0.026×10^6 Btu/short ton) of ore; for classification, 0.10×10^8 joules/metric ton (2.8 kWhe/metric ton or 0.026×10^6 Btu/short ton) of ore; for filtration, 0.015×10^8 joules/metric ton (0.42 kWhe/metric ton or 0.004×10^6 Btu/short ton) of ore

Natural Gas: for crushing and screening, 0.36 cu meters/metric ton (11.6 cu ft/short ton) of ore; for wet grinding, 0.52 cu meters/metric ton (16.8 cu ft/short ton) of ore; for digestion, 2.6 cu meters/metric ton (84 cu ft/short ton) of ore; for classification, 0.53 cu meter/metric ton (17 cu ft/short ton) of ore; for filtration, 0.34 cu meter/metric ton (11 cu ft/short ton) of ore

5. Waste Streams -

Recycling of acid leach liquor is not practical because high concentrations of solutes interfere. Neutralization of acid waste liquors is necessary if seepage or discharge of wastes take place.

With the exception of the bulk of uranium isotopes, the radioactive decay products, including the most toxic isotope, radium 226, remain in the tailings.

6. EPA Source Classification Code - None

7. References -

(1) Private communication with members of the BCL staff who have consulted with producers on energy requirements and specifics of operation.

(2) Development Document for Effluent Guidelines and Standards of Performance, Ore Mining and Dressing Industry (Draft), U. S. Environmental Protection Agency, Washington, D.C. (prepared by Calspan Corp., Buffalo, N. Y.), April 1975.

(3) DeCurlo, Joseph A., and Shortt, Charles E., Chapter on Uranium, Mineral Facts and Problems, 1970, Bureau of Mines Bulletin 650, Bureau of Mines, U. S. Department of the Interior, Washington, D.C., pp 219-242.

(4) Baroch, Charles T., Chapter on Uranium, Mineral Facts and Problem, 1965, Bureau of Mines Bulletin 630, Bureau of Mines, U. S. Department of the Interior, Washington, D. C., pp 1007-1035.

URANIUM - URANIUM CONTAINING DEPOSITS PROCESS NO. 5

Solvent Extraction of Uranium from the Pregnant Leach Solution

1. Function - Direct precipitation of uranium by raising the pH is effective only with the alkaline leach (which is described in a previous section, Process No. 3). If it were applied to the acid leach, most heavy metals, particularly iron, would be precipitated as contaminants. To avoid this, uranium (or vanadium and molybdenum) is concentrated by a factor of five or more by solvent extraction or ion exchange. The latter is described in the next section, Process No. 6

   In the solvent extraction process, polar solvents such as tertiary amines or alkylphosphates in a nonpolar diluent such as kerosine unite with uranium salts in the clarified aqueous leach when the two immersible mediums are mixed. After mixing, the supernatent uranium-loaded organic layer is decanted for stripping.

   The reverse of solvent extraction is accomplished in the stripping step. The pregnant organic solvent is stripped with an aqueous sodium chloride solution. In turn, uranium oxide is precipitated from this aqueous solution with ammonia. The precipitate is filtered, dried, and packaged in drums as "yellow cake".

2. Input Materials - Pregnant leach solution; kerosine (nonpolar diluent for polar solvents) 1.75 liters/metric ton (0.42 gals/metric ton) of ore; polar solvents, tertiary amines, alkyl phosphates; sodium chloride (in stripping solution), 4.4 kq/metric ton (8.8 lbs/short ton) of ore; ammonia (for precipitating uranium oxide from the stripping solution), 0.8 kg/metric ton (1.6 lbs/short ton) of ore; water.

3. Operating Parameters -

   Temperature: Room temperature

   Pressure: Atmospheric

4. Utilities - Amount used based on ore containing 0.20 percent uranium oxide

Electric Energy: for solvent extraction, 0.061×10^8 joules/metric ton (1.7 kWhe/metric ton or 0.016×10^6 Btu/short ton) of ore; for stripping, 0.026×10^8 joules/metric ton (0.73 kWhe/metric ton or 0.007×10^6 Btu/short ton) of ore; for precipitation, 0.018×10^8 joules/metric ton (0.51 kWhe/metric ton or 0.005×10^5 Btu/short ton) of ore; for drying, 0.052×10^8 joules/metric ton (1.5 kWhe/metric ton or 0.014×10^6 Btu/short ton) of ore

Natural Gas: for drying, 8.14 cu meters/metric ton (261 cu ft/short ton) of ore

5. Waste Streams -

Acid leach mills discharge a portion of the acid leach.

Excess free acid in leach liquor and extraction raffinates (non-soluble portions) may be recycled. Acid may be used to condition incoming ores containing acid consuming gangue. Sulfates, however, remain.

Loss of kerosine solvents is in the amount of 1/2000th of water usage. Also losses of tertiary amines and alkyl phosphates occur which are toxic to fish.

Repulped tailings from preceding acid leach contain radium, thorium, and uranium, organics from carbonaceous ores, chlorides, nitrides, and phosphates, and both light and heavy metals

6. EPA Source Classification Code - None

7. References -

(1) Private communication with members of the BCL staff who have consulted with producers on energy requirements and specifics of operation.

(2) Development Document for Effluent Guidelines and Standards of Performance, Ore Mining and Dressing Industry (Draft), U. S. Environmental Protection Agency, Washington, D.C. (prepared by Calspan Corp., Buffalo, N. Y.), April 1975.

(3) DeCurlo, Joseph A., and Shortt, Charles E., Chapter on Uranium, Mineral Facts and Problems, 1970, Bureau of Mines, U. S. Department of the Interior, Washington, D.C., pp 219-242.

(4) Baroch, Charles T., Chapter on Uranium, Mineral Facts and Problems, 1965, Bureau of Mines Bulletin 630, Bureau of Mines, U. S. Department of the Interior, Washington, D.C., pp 1007-1035.

Ion-Exchange Recovery of Uranium from Pregnant Leach Solution (Including the Resin-in-Pulp Ion-Exchange Process)

1. Function - Ion exchange is based upon the same principle as solvent extraction. Polar organic molecules (in the case of solvent extraction) or polymers (in the case of a resin) exchange a mobile ion in their structure for an ion in the leach solution which either has a greater charge or smaller ionic radius. In the ion exchange process, the exchange of ions is between the leach solution and an insoluble resin. It is used to concentrate uranium oxide in both acid and alkaline leach solutions. The method is particularly adaptable to the removal of small amounts of solutes from large volumes of solutions. Uranium is in the leach solution as an oxidized ion complexed with an ionic radical to form trisulfates in acid leach solutions or tricarbonates in alkaline leach solutions. These complexes react with anion exchange resins which absorb the uranium anions. This is done in two ways; either a clarified pregnant uranium solution is passed through fixed packed columns of resins, or pulp-containing slimes and dissolved uranium is concentrated using the "resin-in-pulp" method. In the "resin-in-pulp" process, spherical-shaped resin particles [between 1.65 and 0.83 mm (10 and 20 mesh) in size] are oscillated in baskets in the slimy pregnant pulp. The oscillation prevents accumulation of the solid slimes between the resin particles. The "resin-in-pulp" method eliminates the need for clarification.

Vanadium and molybdenum, common constituents in uranium ores, also may be present in the leach solution as oxidized ions complexed with anionic radicals. While they also react anionically with the exchange resins, the relative degree of affinity for exchange resins can be changed radically by changes in pH of the leach and other controllable factors. Thus, variations in pH, redox potential, multiple columns, and periods of reaction are used to make an ion-exchange process specific for a desired product.

After absorption of the uranium, the resin is eluted with a dilute solution of sulfuric acid and sodium chloride. The values are precipitated with a base or hydrogen peroxide. Ammonia is preferred by most mills. Partial neutralization with calcium hydroxide, followed by magnesium hydroxide precipitation, is also used. In the latter case, the resultant solution is treated with milk-of-lime to adjust pH and to remove iron, which is filtered off. Magnesia is added to the clarified solution to precipitate yellow cake. Following filtration, the precipitate is washed with an ammonium sulfate solution and later, water. The yellow cake is then dried on drum driers and with infrared heaters.

2. Input Materials - Pregnant leach solution; resin (recycled); sulfuric acid (elution), 2.6 kg/metric ton (5.2 lbs/short ton) of ore processed; sodium chloride (elution), 10.6 kg/metric ton (21.2 lbs/short ton) of ore processed; lime (precipitation), 2 kg/metric ton (4 lbs/short ton) of ore processed; ammonia (precipitation), 0.8 kg/metric ton (1.6 lbs/short ton) of ore processed

3. Operating Parameters -

Content of pH and redox potential of pregnant solutions is critical. For example, at pH 9, a particular resin will absorb 7 times more vanadium than uranium from a leach solution; at pH 11, the ratio is reversed, with 33 times as much uranium as vanadium being captured.

4. Utilities -

Electrical Energy: for ion exchange, 0.27×10^8 joules/metric ton (7.5 kWhe/metric ton or 0.071×10^6 Btu/short ton) of ore processed; for stripping, first precipitation and filtration, second precipitation and filtration, 0.17×10^8 joules/metric ton (4.6 kWhe/metric ton or 0.044×10^6 Btu/short ton) of ore processed; for drying, 0.083×10^8 joules/metric ton (2.3 kWhe/metric ton or 0.022×10^6 Btu/short ton) of ore processed

Natural Gas: for stripping, first precipitation and filtration, second precipitation and filtration, 1.87 cu meters/metric ton (60 cu ft/short ton) of ore processed; for drying, 7.0 cu meters/metric ton (224 cu ft/short ton) of ore processed

5. Waste Streams -

Radium constituents of the ore remain in the raffinate and is a serious liquid waste emissions problem.

Vanadium, if present in the ore, and hence in the pregnant leach, will remain in the raffinate. If present in recoverable amounts, the raffinate will undergo solution or solvent extraction.

Worn out resins are occasionally discarded.

Solid tailings from resin-in-pulp ion exchange operations remain with the raffinate.

Other metals, organics, ion-exchange resins (about 30 ppm) appear in the waste streams. Suspended solids also are on the high side.

6. EPA Source Classification Code - None

7. References -

(1) Private communication with members of the BCL staff who have consulted with producers on energy requirements and specifics of operation.

(2) Development Document for Effluent Guidelines and Standards of Performance, Ore Mining and Dressing Industry (Draft), U. S. Environmental Protection Agency, Washington, D.C. (prepared by Calspan Corp., Buffalo, N. Y.), April 1975.

(3) DeCurlo, Joseph A., and Shortt, Charles E., Chapter on Uranium, Mineral Facts and Problems, 1970, Bureau of Mines Bulletin 650, Bureau of Mines, U. S. Department of the Interior, Washington, D.C., pp 219-242.

(4) Baroch, Charles T., Chapter on Uranium, Mineral Facts and Problems, 1965, Bureau of Mines Bulletin 630, Bureau of Mines, U. S. Department of the Interior, Washington, D.C., pp 1007-1035.

Vanadium

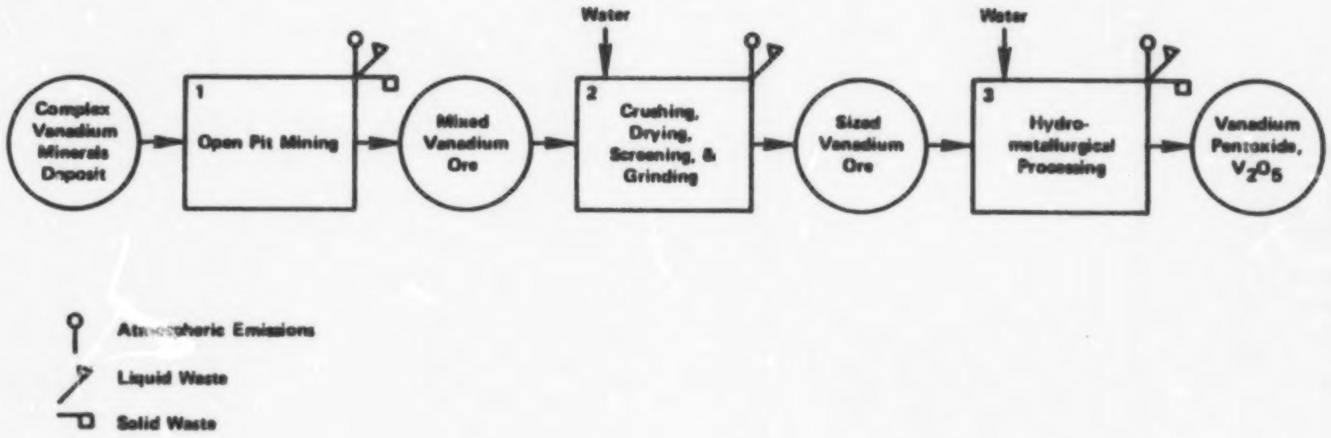
The United States has been a leading producer of vanadium for over two decades. In this commodity, we are almost self-sufficient although some vanadium materials, principally ferrovanadium, continue to be imported. The consumption of vanadium in the U.S. is approaching 5500 tons per year. Domestic production falls about 500 to 600 tons per year short of that amount. The bulk of the domestic production is as byproduct vanadium from such sources as uranium-vanadium ores, vanadium-bearing oil residues, spent catalysts, vanadium-bearing residues from titanium dioxide and titanium tetrachloride production, vanadium-containing slags, and vanadium-bearing ferrophosphorus obtained in elemental phosphorus production.

Vanadium is about twice as abundant as copper and zinc, and ten times as abundant as lead. However, it is quite dispersed for the most part which makes the recovery impractical from many of its known "rich" concentrations except as byproduct in the recovery of other materials. The single U.S. exception to the above is the Potash Sulfur Springs (also known as Wilson Springs), deposit in Garland County, Arkansas (near Hot Springs). Here the vanadium ore which contains about 1 percent V_2O_5 equivalent, occurs as poorly defined bodies in irregular masses of argillic altered rock of both an igneous intrusion (alkalic) and the bordering sedimentary strata. The ore rarely occurs as discrete vanadium minerals but those that have been identified are: montroseite, fervanite, and hewettite. Due to these complexities, the raw material for the purposes of this report is termed, complex vanadium mineral deposit.

The mined ore from the Potash Sulfur Springs deposit is processed in a Hot Springs Arkansas processing plant (which also handles byproduct ferrophosphorus obtained in elemental phosphorus production, for vanadium recovery) to result in pure vanadium oxide (99.8 percent) or ammonium metavanadate, NH_4VO_3. The plant can also produce a technical grade vanadium pentoxide (86 percent V_2O_5 minimum) but does not usually do so. Thus the usual products are:

(a) Pure vanadium oxide
(b) Ammonium metavanadate

Vanadium


Water
Water
Complex Vanadium Minerals Deposit
1
Open Pit Mining
Mixed Vanadium Ore
2
Crushing, Drying, Screening, & Grinding
Sized Vanadium Ore
3
Hydro-metallurgical Processing
Vanadium Pentoxide, V_2O_5
Atmospheric Emissions
Liquid Waste
Solid Waste

VANADIUM - COMPLEX VANADIUM MINERAL DEPOSIT PROCESS NO. 1

Open Pit Mining

1. Function - Most of the vanadium mined in the U. S. was produced from the uranium-vanadium deposits of the Colorado Plateau and from the complex Potash Sulfur Springs vanadium mineral deposit near Hot Springs, Arkansas. Recovery of vanadium from the carnotite ores of the Colorado Plateau are covered under "Uranium". The Arkansas deposit is the only U. S. deposit mined for vanadium only. Mining is by open pit methods using standard drilling, blasting, digging, and loading equipment. The deposit is not uniform. It contains alternate "pockets" of lean and rich ores necessitating assays of drill holes spaced at 6.1 meters (20-ft) centers. Ore is produced in a controlled mix to provide a uniform feed to the mills.

2. Input Materials (based on analogous operations) - Explosives: about 0.5 kg/metric ton (1.0 lb/short ton) of ore; water.

3. Operating Parameters -

   Temperature: Ambient

   Pressure: Atmospheric

4. Utilities (based on analogous operations) -

   Electrical energy: 0.22×10^8 joules/metric ton (6.0 kWhe/metric ton or 0.057×10^6 Btu/short ton) of ore
   Diesel fuel (or equivalent): 1.2 liters/metric ton (0.28 gal/short ton) of ore

5. Waste Streams -

   Air emissions normally associated with open pit mining: dust, particulates from blasting and loading operations

   Raw mine water effluent flows at the rate of 11.3 cu meters/min (3000 gals/min). Manganese content is high, 6.8 mg/liter.

   Owing to the "pockety" nature of the deposit, waste rock may be appreciable.

6. EPA Source Classification Code - None

7. References -

(1) Development Document for Effluent Limitations Guidelines and Standards of Performance, Mining and Ore Dressing Industry, U. S. Environmental Protection Agency, (prepared by Calspan Corp., Buffalo, N. Y.), April 1975.

(2) Private communication with members of the BCL staff who have consulted with producers on energy requirements and specifics of operation.

(3) Griffith, Robert F., Chapter on Vanadium, Mineral Facts and Problems, 1970, Bureau of Mines Bulletin 650, Bureau of Mines, U. S. Department of the Interior, pp 417-430.

VANADIUM - COMPLEX VANADIUM MINERAL DEPOSIT PROCESS NO. 2

Crushing, Drying, Screening, and Grinding

1. Function - Ore is crushed, dried, then ground and classified by screening to minus 1.17 mm (-14 mesh) in preparation for the next step in processing--mixing with salt, and pelletizing. Crushed ore is dried in a rotary kiln dryer which is equipped with a wet-scrubber.

2. Input Materials - Ore containing 1.5-2.0 percent V_2O_5 from open-pit mine and water.

3. Operating Parameters -

   Temperature: Roasting, 850C (1562)

   Pressure: Atmospheric

4. Utilities -

   Electric Energy: 0.73 x 10^8 joules/metric ton (20.4 kWhe/metric ton or 0.19 x 10^6 Btu/short ton) of ore
   Natural Gas: 9.4 cu meters/metric ton (302 cu ft/short ton of ore

5. Waste Streams -

   Dust, particulates in crushing and grinding

   Bleed from wet scrubber on the rotary kiln dryer has a pH of 7.8, a total dissolved solids (T.D.S.) content of about 7500 mg/l, and a chloride content of about 4000 mg/l.

6. EPA Source Classification Code - None

7. References -

   (1) Development Document for Effluent Limitations Guidelines and Standards of Performance, Mining and Ore Dressing Industry, U. S. Environmental Protection Agency, (prepared by Calspan Corp., Buffalo, N. Y.), April 1975.

   (2) Private communication with members of the BCL staff who have consulted with producers on energy requirements and specifics of operation.

(3) Griffith, Robert F., Chapter on Vanadium, Mineral Facts and Problems, 1970, Bureau of Mines Bulletin 650, Bureau of Mines, U. S. Department of the Interior, pp 417-430.

Hydrometallurgical Processing

1. **Function** - In the hydrometallurgical processing of ore to vanadium pentoxide, the crushed and dried ore is ground and screen classified to minus 1.17 mm (-14 mesh), and then mixed with about 7 percent by weight of salt, following which it is pelletized, and roasted at 850 C (1560 F) to convert vanadium in the ore to soluble sodium vanadate, $NaVO_3$. It is then quenched in water, after which the water solution is acidified with sulfuric acid to a pH of 2.5-3.5. The resulting sodium decavanadate, $Na_6V_{10}O_{28}$, is concentrated by solvent extraction and in the process freed of impurities such as sodium from the roasting operation, and calcium, iron, phosphorous, and silica from the ore; these impurities remain in the raffinate. Slightly soluble ammonium vanadate, NH_4VO_3, is precipitated from the stripping solution with ammonia. The ammonium vanadate is then calcined to yield vanadium pentoxide, V_2O_5.

2. **Input Materials** - minus 1.17 mm (-14 mesh) ore; salt, from 6-10 percent by weight of ore; sulfuric acid (additions to water solution of sodium vanadate to yield a pH range of 2.5 to 3.5); tertiary amines (solvent extraction) 0.61 Kg/metric ton (1.25 lb/short ton) of ore (based on analogous operation); ammonium hydroxide (additions to precipitate NH_4VO_3) 0.65 Kg/metric ton (1.30 lb/short ton) of ore (based on analogous operation)

3. **Operating Parameters** -

   The temperature of the salt roast is 850 C (1560 F). Quenching in water follows roasting. The pH of this water leach containing vanadium as soluble sodium decavanadate Na6V10028, is adjusted to 2.5-3.5 with H_2SO_4 additions. Vanadium in this solution is then further concentrated by solvent extraction. Stripped liquor from this operation is heated and the pH adjusted with ammonia to convert the sodium decavanadate $Na_6V_{10}O_{28}$ to ammonium vanadate, $(NH_4)_4V_4O_{12}$. The solution is cooled, fed to continuous cooling crystalizers which crystallize out ammonium vanadate.

4. Utilities - (based on analogous operation)

Electric energy: for salt roasting, 0.049×10^8 joules/metric ton (1.35 kWhe/metric ton or 0.013×10^6 Btu/short ton) of ore; for leaching; 0.049×10^8 joules/metric ton (1.35 kWhe/metric ton or 0.013×10^6 Btu/short ton) of ore; for solvent extraction, 0.049×10^8 joules/metric ton (1.35 kWhe/metric ton or 0.013 $\times 10^6$ Btu/short ton) of ore; for precipitation and calcining, 0.011×10^8 joules/metric ton (0.3 kWhe/metric ton or 0.003×10^6 Btu/short ton) of ore

Natural Gas: for salt roasting, 67 cu meters/metric ton (2140 cu ft/short ton) of ore; for leaching, 3.9 cu meters/metric ton (124 cu ft/short ton) of ore; for solvent extraction, 8.4 cu meters/metric ton (268 cu ft/short ton) of ore; for precipitation and calcining, 11 cu meters/metric ton (354 cu ft/short ton) of ore

5. Waste Streams -

Stack exhausts from rotary kiln drying and roasting cycles are cleaned with wet scrubbers.

Effluent streams from leaching and solvent extraction are sent to tailing ponds where "brown mud" waste material from nearby alumina plants may be used to clarify the waste water before it is discharged to streams.

Streams from leaching, solvent extraction, and wet scrubbers on the dryer and salt roast operations account for 70 percent of the effluent streams.

The leach and solvent extraction effluent (pH, 3.5) contains extremely high amounts of dissolved sulfate, 26,000 mg/l. The chloride content is also appreciable, 7,900 mg/l.

The salt roast scrubber bleed (pH, 2.5) contains extremely high amounts of calcium (78,000 mg/l) and chloride (about 60,000 mg/l.

Effluents from the leach and solvent extraction plant (T.D.S., about 40,000 mg/liter) and the salt roast scrubber bleed (T.D.S., about 50,000 mg/liter) are segregated in the plant to avoid the generation of voluminous calcium sulfate precipitates. They are discharged into tailing pond at the same point after being diluted 10:1 just before discharge. Discharges from the tailing pond to area streams are made only during wet seasons. The major emission associated with calcining is high nitrogen (thousands of ppm) in the effluent from the wet scrubber.

6. EPA Source Classification Code - None

7. References -

(1) Development Document for Effluent Limitations Guidelines and Standards of Performance, Mining and Ore Dressing Industry, U. S. Environmental Protection Agency (prepared by Calspan Corp., Buffalo, N. Y.), April 1975.

(2) Private communication with members of the BCL staff who have consulted with producers on energy requirements and specifics of operation.

(3) Griffith, Robert F., Chapter on Vanadium, Mineral Facts and Problems, 1970, Bureau of Mines Bulletin 650, Bureau of Mines, U. S. Department of the Interior, pp 417-430.

APPENDIX A

Population of U.S. Metal Mining and Beneficiation Companies

Bauxite Mining and Beneficiating Companies

(1) General Refractories Company
(Southern Mines)
Stevens Pottery
Georgia 31088

(2) Eufaula Bauxite Mining Company
P. O. Box 556
Eufaula, Alabama 36027

(3) A. P. Green Refractories
Eufaula
Alabama 36027

(4) Harbison-Walker Refractories
Company, Div. of Dresser
Industries, Inc.
Eufaula, Alabama 36027

(5) Wilson-Sneed Mining Co., Inc.
P. O. Box 568
Eufaula, Alabama 36027

(6) Aluminum Company of America
P. O. Box 300
Bauxite, Arkansas 72011

(7) American Cyanamid Company
Industrial Chemicals and
Plastics Division
P. O. Box 246
Benton, Arkansas 72015

(8) Englehard Minerals & Chemicals
Corporation
Minerals and Chemicals Div.
Little Rock, Arkansas 77206

(9) Reynolds Mining Corporation
P. O. Box 398
Bauxite, Arkansas 72011

(10) Stauffer Chemical Company
Industrial Chemical Division
P. O. Box 188
North Little Rock, Arkansas
72115

Antimony Ore Producers

(1) U.S. Antimony Corporation (Babbit Mine)
P.O. Box 643
Thompson Falls, Montana 59873

(2) Hecla Mining Company (Consolidated Silver Project)
P.O. Box 259
Osburn, Idaho 83849

(3) Sunshine Mining Company (Sunshine Mine)
P.O. Box 1080
Kellogg, Idaho 83837

Beryllium Ore Producers

(1) Brush Wellman, Inc.
(Spor Mountain Operations)
P. O. Box
Delta, Utah

(2) U. S. Beryllium Corporation
303 Bon Durant Building
Pueblo, Colorado 81003

(3) Jack Pendleton
Custer
South Dakota 57730

(4) John Carter
608 St. Cloud Avenue
Rapid City, South Dakota 57701

Columbium-Tantalum Ore Producers

(1) Curtis Nevada Mines, Inc.
P.O. Box 133
Topaz, California 96133

Raw Materials

The minerals of importance for the production of columbium and tantalum are columbite, $(Fe,Mn)(Cb,Ta)_2O_6$; tantalite, $(Fe,Mn)(Ta,Cb)_2O_6$; pyrochlore, $NaCaCb_2O_6F$; and several complex rare earth-content minerals such as euxenite, $(Ce,Y,Th,Ca,U)(Cb,Ta,Ti)_2O_6$.

Columbite and tantalite are actually a series of oxide mixtures including oxides of iron and manganese in chemical bond wherein the mineral is termed columbite when the amount of columbium (niobium) is high, and tantalite when more tantalum than columbium is present. As mentioned previously, columbite-tantalite mineralization is commonly of pegmatitic occurrence (or in placers derived from pegmatite weathering). The mineralization of the ore being mined in California includes columbite, tantalite, yttrocerite and samarskite (rare earth minerals), siserskite (platinum metals group), and the noble metals, gold and silver.

Columbium-Tantalum Products

The products resulting from the mining and beneficiating of ores for the production of columbium and tantalumin the U.S. are the concentrates of the appropriate minerals, columbite and tantalite.

Copper Mining and Beneficiating Companies

(1) American Smelting and Refining
Company
San Xavier Unit
P. O. Box 111
Sahuarita, Arizona 85629

(2) American Smelting and Refining
Company
Sacation Unit
P. O. Box V
Casa Grande, Arizona 85222

(3) American Smelting and Refining
Company
Mission Unit
P. O. Box 111
Sahuarita, Arizona 85629

(4) American Smelting and Refining
Company
Silver Bell Unit
Silver Bell, Arizona 85270

(5) The Anaconda Company
Primary Metals Division
Butte Operations
P. O. Box 1971
Butte, Montana 59701

(6) The Anaconda Company
Primary Metals Division
Yerington Mines
P. O. Box 1000
Weed Heights, Nevada 89443

(7) APCO Oil Corporation
Minerals Division
Cove Meadow Copper Mine
P. O. Box 6
Wadsworth, Nevada 89442

(8) Anamax Mining Company
Twin Buttes Operation
P. O. Box 127
Suharita, Arizona 85629

(9) Cities Service Company
North American Chemicals
& Metals Group
Miami Copper Operations
P. O. Box 100
Miami, Arizona 85539

(10) Cities Service Company
North American Chemicals
& Metals Group
Pinto Valley Operations
P. O. Box 727
Miami, Arizona 85539

(11) Cities Service Company
North American Chemicals
& Metals Group
Copperhill Operations
Copperhill, Tennessee 37317

(12) Cobre Mines, Inc.
Cobre Mine
Box 378
Hanover, New Mexico 88041

(13) Continental Copper, Inc.
Control Mine
P. O. Box 622
Oracle, Arizona 85623

(14) Cyprus Mines Corporation
Bruce Mine Division
P. O. Box 457
Bagdad, Arizona 86321

(15) Duval Corporation
Mineral Park Property
P. O. Box 1271
Kingman, Arizona 86401

(16) Duval Corporation
Esperanza Property
P. O. Box 38
Sahuarita, Arizona 85629

(17) Duval Sierrita Corporation
Sierrita Property
P. O. Box 125
Sahuarita, Arizona 85629

(18) Eagle-Pilcher Industries, Inc.
Creta Operation
P. O. Box 16
Olustee, Oklahoma 73560

(19) Earth Resources Company
Nacimiento Copper Mine
P. O. Box 202
Cuba, New Mexico 87013

(20) El Paso Natural Gas Company
Emerald Isle Plant
P. O. Box 1313
Kingman, Arizona 86401

(21) Federal Resources Corporation
Bonney-Miser's Chest and
'85' Mines
P. O. Box A
Lordsburg, New Mexico 88045

(22) Goldfield Corporation
San Pedro Copper Mine
101, 65 East Nasa Boulevard
Melbourne, Florida 32901

(23) Hecla Mining Company
Lakeshore Copper Property
P. O. Box 493
Casa Grande, Arizona 85222

(24) Homestake Copper Company
650 California Street
San Francisco, California
54108

(25) Imperial Consolidated
Copper Company
Ox Hide Mine
Inspiration, Arizona 85537

(26) Inspiration Consolidated
Copper Company
Christmas Division
Inspiration, Arizona 85537

(27) Inspiration Consolidated
Copper Company
Sanchez Project
Inspiration, Arizona 85537

(28) Inspiration Consolidated
Copper Company
Inspiration Division
Inspiration, Arizona 85537

(29) Imperial Copper Company
11634 Davis Street
Sunnymead, California 92388

(30) Kennecott Copper Corporation
Ray Mines Division
Hayden, Arizona 85235

(31) Kennecott Copper Corporation
Utah Copper Division
P. O. Box 11299
Salt Lake City, Utah 84111

(32) Kennecott Copper Corporation
Chino Mines Division
Hurley, New Mexico 88043

(33) Kennecott Copper Corporation
Nevada Mines Division
McGill, Nevada 89313

(34) Kerramerican, Inc.
Blue Hill Mine
P. O. Box D
Blue Hill, Maine 04614

(35) Keystone Wallace Resources
702 South Main Street
Moab, Utah 84532

(36) Magma Copper Company
San Manuel Division
P. O. Box M
San Manuel, Arizona 85631

(37) Magma Copper Company
Superior Division
Box 37
Superior, Arizona 85273

(38) McAlester Fuel Company
Zonia Operation
Route 1
Kirkland, Arizona 86332

(39) Micro Copper Corporation
Lisbon Valley Mine
Uranium Building
Moab, Utah 84532

(40) Phelps Dodge Corporation
Tyrone Branch
Tyrone, New Mexico 88065

(41) Phelps Dodge Corporation
Copper Queen Branch
Bisbee, Arizona 85603

(42) Phelps Dodge Corporation
Morenci Branch
Morenci, Arizona 85540

(43) Phelps Dodge Corporation
New Cornelia Branch
Ajo, Arizona 85321

(44) Pima Mining Company
Box 7187
Tucson, Arizona 85725

(45) Ranchers Exploration &
Development Corporation
Big Mike Mine
620 Metaky Street
Winnemucca, Nevada 89445

(46) Ranchers Exploration &
Development Corporation
Ranchers Bluebird Mine
Box 880
Miami, Arizona

(47) Ranchers Exploration &
Development Corporation
Old Reliable Mine
149 Main Street
Mammoth, Arizona

(48) Salmon Canyon Copper Co.
P. O. Box 891
Jamestown, North Dakota
58401

(49) Toledo Mining Company
OK Mine
323 Newhouse Building
Salt Lake City, Utah 84111

(50) USNR Mining & Minerals Inc.
Copper Leach Mine
P. O. Box 1256
Silver City, New Mexico
88061

(51) White Pine Copper Company
White Pine
Michigan 49971

Gold Ore Processing Companies

(1) APCO Oil Corporation
Minerals Division
P. O. Box 51
Downieville, California 95936

(2) APCO Agricola Mines
Independence Mine
P. O. Box 397
Battle Mountain, Nevada 85820

(3) Carlin Gold Mining Company
P. O. Box 973
Carlin, Nevada 89822

(4) Coronado Silver Corporation
Los Lagos Office
Rollinsville, Colorado 80474

(5) Cortez Gold Mines
Cortez
Nevada 89821

(6) Homestake Mining Company
P. O. Box 875
Lead, South Dakota 57754

(7) Inland Empire Milling & Mining Corporation
432 North "G" Street
San Bernardino, California 92410

(8) L & K Development Corporation
3450 Glen Avenue
Oroville, California 95965

(9) The Old Ontario Mining Company
P. O. Box 93
Duncan, Arizona 85534

(10) Picacho Development Corp.
c/o Continental Diversified Industries, Inc.
433 Maple Avenue
Westbury, New York 11590

(11) Sultan Sawmill & Mining Co.
1808 8th Avenue
Seattle, Washington 98101

(12) United States Platinum Inc.
2301 Oddie Blvd., #123
Reno, Nevada 89503

(13) U. V. Industries, Inc
P. O. Box 1170
Fairbanks, Alaska 99701

Iron Ore Processing Companies

(1) Adams Mine
The Cleveland-Cliffs Iron Company
Kirkland Lake
Ontario, Canada

(2) Bethlehem Mines Corporation
Bethlehem
Pennsylvania 18016

(3) Butler Taconite
The Hanna Mining Company
Cooley, Minnesota

(4) Caland Ore Company Ltd.
Inland Steel Company
Atikokan
Ontario, Canada

(5) Cities Service Company
Copperhill Operations
Copperhill, Tennessee 37317

(6) The Cleveland-Cliffs Iron Company
1460 Union Commerce Building
Cleveland, Ohio 44115

(7) Coons Pacific Company
2521 First Avenue
Hibbing, Minnesota 55746

(8) Empire Iron Mining Company
The Cleveland-Cliffs Iron Company
Eagle Mills, Michigan

(9) Erie Mining Company
Pickands Mather & Co.
P. O. Box 847
Hoyt Lakes, Minnesota
55750

(10) Eveleth Taconite Company
Oglebay Norton Company
Thunderbird, Minnesota

(11) Hanna Iron Ore Division
National Steel Corporation
100 Erieview Plaza
Cleveland, Ohio 44114

(12) The Hanna Mining Company
100 Erieview Plaza
Cleveland, Ohio 44114

(13) Inland Steel Company
30 West Monroe Street
Chicago, Illinois 60603

(14) Jackson County Iron Co.
Inland Steel Company
Black River Falls
Wisconsin

(15) Jones & Laughlin Steel Corp.
3 Gateway Center
Pittsburgh, Pennsylvania
15230

(16) Kaiser Steel Corporation
Kaiser Center
300 Lakeside Drive
Oakland, California 94612

(17) Lone Star Steel Company
P. O. Box 35888
2200 West Mockingbird Lane
Dallas, Texas 75235

(18) Luck Mining Company
215 Market Street, Room 810
San Francisco, California
94105

(19) Marquette Iron Mining Co.
The Cleveland-Cliffs Iron Company
Humboldt, Michigan

(20) Meramec Mining Company
250 Park Avenue
New York, New York 10017

(21) The Mesaba-Cliffs Mining Company
The Cleveland-Cliffs Iron Company
Coleraine, Minnesota

(22) N L Industries, Inc.
Titanium Pigment Div. (USTP)
100 Chevalier Avenue
South Amboy, New Jersey
08879

(23) The Negaunee Mine Company
The Cleveland-Cliffs Iron Company
Negaunee, Michigan

(24) Nevada-Barth Corporation
P. O. Box 1057
Winnemucca, Nevada 89445

(25) Oglebay Norton Company
1200 Hanna Building
Cleveland, Ohio 44115

(26) Pacific Isle Mining Company
Inland Steel Company
Ishpeming, Michigan 49849

(27) Pickands Mather & Co.
1100 Superior Avenue
Cleveland, Ohio 44114

(28) Pilot Knob Pellet Company
The Hanna Mining Company
Pilot Knob, Missouri

(29) Pioneer Pellet Plant
The Cleveland-Cliffs Iron Company
Eagle Mills, Michigan

(30) Pittsburgh Pacific Company
2521 First Avenue
Hibbing, Minnesota 55746

(31) Reserve Mining Company
Silver Bay
Minnesota 55614

(32) Rhude & Fryberger, Inc.
P. O. Box 66
Hibbing, Minnesota 55746

(33) Sherman Mine
The Cleveland-Cliffs Iron Company
Temagami, Ontario
Canada

(34) The Standard Slag Company
1200 Stambaugh Building
Youngstown, Ohio 44501

(35) Tex-Iron, Inc.
P. O. Box 367
Cushing, Texas 75760

(36) Tilden Mining Company
The Cleveland-Cliffs Iron Company
Tilden Township
Michigan

(37) United States Pipe and Foundry Company
3300 First Avenue, North
Birmingham, Alabama 35202

(38) United States Steel Corp.
600 Grant Street
Pittsburgh, Pennsylvania
15230

(39) Utah International Inc.
550 California Street
San Francisco, California
94104

(40) CF & I Steel Corporation
Sunrise Mine
P. O. Box 457
Guernsey, Wyoming 82214

(41) CF & I Steel Corporation
Comstock Mine
P. O. Box 100
Center City, Utah 84720

(42) Cranberry Magnetite Corp.
Greenback Industries, Inc.
P. O. Box 63
Greenback, Tennessee 37742

(43) Cranberry Magnetite Corp.
Greenback Industries, Inc.
Cranberry, North Carolina
28614

(44) Dunbar Layton Mining
P. O. Box 267
Lumpkin, Georgia 31815

(45) Glenwood Mining Company
Glenwood
Alabama 36034

(46) Halecrest Company, Inc.
Talmadge Road
Edison, New Jersey 08817

(47) Halecrest Company, Inc.
Mt. Hope Iron Mine
RD No. 1
Wharton, New Jersey 07885

(48) Leber Mining Company
Falcon Mine
Stamps, Arkansas 71860

(49) Mahoning Ore & Steel Company
Mahoning Mine
Box 308
Kelly Lake, Minnesota 55754

(50) Shook & Fletcher Supply Co.
1814 First Avenue North
Birmingham, Alabama 35202

(51) J. R. Simplot Company
Simplot Iron Mines
Palisades Nevada

(52) Snyder Mining Company
Div. Shenango Furnace Company
Whiteside Mine
Box 218
Buhl, Minnesota 55713

(53) Republic Steel Corporation
Adirondack Ore Mines
Mineville, New York 12956

Lead-Zinc Ore Processing Companies
(Lead Predominating)

(1) Allied Chemical Corporation
Industrial Chemicals Div.
P. O. Box 228
Boulder, Colorado 80302

(2) AMAX Lead and Zinc, Inc.
Buick Mine
Boss, Missouri 65440

(3) AMAX Lead and Zinc, Inc.
7733 Forsyth Boulevard
Clayton, Missouri 63105

(4) American Smelting &
Refining Co.
Leadville Unit
Box 936
Leadville, Colorado 80461

(5) The Bunker Hill Company
P. O. Box 29
Kellogg, Idaho 83837

(6) Camp Bird Colorado, Inc.
Duray
Colorado 81427

(7) Cominco American Incorporated
Magmont Mine
Bixby, Missouri 65439

(8) Day Mines, Inc.
506-1/2 Cedar Street
Wallace, Idaho 83873

(9) Kennecott Copper Corporation
Tintic Division
P. O. Box 250
Eureka, Utah 84628

(10) Ozark Lead Company
Rural Branch
Sweetwater, Missouri 63680

(11) Pend Oreille Mines & Metals
Company
923 Old National Bank Bldg.
Spokane, Washington 99201

(12) Pend Oreille Mines & Metals
Company
Metaline Falls
Washington 99153

(13) Rico Argentine Mining Co.
Rico
Colorado 81332

(14) St. Joe Minerals Corporation
250 Park Avenue
New York, New York 10017

(15) St. Joe Minerals Corporation
Edwards Mine
Balmat, New York 13609

(16) St. Joe Minerals Corporation
Fletcher Mine
Bonne Terre, Missouri 63628

(17) St. Joe Minerals Corporation
Brushy Creek
Bonne Terre, Missouri 63628

(18) St. Joe Minerals Corporation
Indian Creek
Bonne Terre, Missouri 63628

(19) St. Joe Minerals Corporation
Viburnam
Bonne Terre, Missouri 63628

Zinc-Lead Ore Processing Companies
(Zinc Predominating)

(1) American Smelting & Refining
Refining Company
Mascot Operations
Mascot, Tennessee 37806

(2) American Smelting &
Refining Company
New Market Mine
P. O. Box 66
New Market, Tennessee
37820

(3) American Smelting &
Refining Company
Deming Mill
P. O. Box 1037
Deming, New Mexico 88030

(4) American Smelting &
Refining Company
Ground Hog Unit
P. O. Box 186
Vanadium, New Mexico 88073

(5) Cerro Spar Corporation
P. O. Box 213
Salem, Kentucky 42078

(6) Eagle-Picher Industries Inc.
Metal Mining Department
Illinois-Wisconsin Operation
P. O. Box 1040
Galena, Illinois 61036

(7) Hecla Mining Company
Hecla Building
Wallace, Idaho 83873

(8) Hydro Nuclear Corporation
Suite 700
First National Bank Bldg. E.
Albuquerque, New Mexico 87108

(9) Idarado Mining Company
Ouray
Colorado 81427

(10) Ivey Construction Company
128 High Street
Mineral Point, Wisconsin
53565

(11) Minerva Oil Company
Fluorspar Division
P. O. Box 531
Eldorado, Illinois 62930

(12) The New Jersey Zinc Company
Austinville Mine
Austinville, Virginia 24212

(13) The New Jersey Zinc Company
Friedenville Mine
R. D. 1
Center Valley, Pennsylvania
18034

(14) The New Jersey Zinc Company
Sterling Mine
Plant Street
Ogdensburg, New Jersey 07439

(15) The New Jersey Zinc Company
Jefferson City Mine
P. O. Box 32
Jefferson City, Tennessee
37760

(16) The New Jersey Zinc Company
Gilman Mine
P. O. Box 118
Gilman, Colorado 81634

(17) Ozark Mahoning Company
Johnson Works
Rosiclare, Illinois 62982

(18) Resurrection Mining Company
Leadville
Colorado

(19) E. G. Sommerlath Enterprises
33740 Lindell Boulevard
Marion, Kentucky 42064

(20) Standard Metals Corporation
Silverton Operations
P. O. Box 247
Silverton, Colorado 81423

(21) United States Steel Corp.
Zinc Mine
Jefferson City, Tennessee
37760

(22) U. V. Industries, Inc.
Bullfrog Mill
P. O. Box 406
Hanover, New Mexico
88041

(23) U. V. Industries, Inc.
Hanover Mine
P. O. Box 406
Hanover, New Mexico
88041

(24) U. V. Industries, Inc.
Princess Mine
P. O. Box 406
Hanover, New Mexico
88041

Manganese-Content Ore Producers

(1) Hanna Mining Company
Lauretta Manganiferous
Mine Project
Crosby, Minnesota 56441

(2) Luck Mining Company
P. O. Box 29
Silver City, New Mexico
88061

(3) The New Jersey Zinc Company
Sterling Mine
Plant Street
Ogdensburg, New Jersey
07439

Raw Materials

Manganese occurs in a great many minerals that are widely distributed in the earth's crust. Commercially, the most important minerals are the oxides, manganite ($Mn_2O_3 \cdot H_2O$), and pyrolusite (MnO_2). World production outside the U. S. is almost entirely from oxides. In the U. S., the oxide minerals are found with the carbonate mineral rhodocrosite ($MnCO_3$), as at Butte, Montana, in small quantities. The manganese oxides predominate in the Minnesota Cuyuna Range ore which contains 13.75 percent manganese as mined. Presumably the oxides also are the prevalent form of manganese in the New Mexico mine recovery of manganiferous iron ore. The manganese minerals in the New Jersey zinc recovery operations have not been identified.

Manganese Ore Products

As previously indicated, manganese is recovered in the form of manganiferous iron ore concentrate from the Minnesota and New Mexico mining operations and as ferromanganese alloy from the smelting of the New Jersey zinc ore (the zinc ore is smelted in Pennsylvania). The latter product is designated as manganese-in-residue on the lead-zinc process flow diagram.

Mercury Producers

(1) Buena Vist Mines, Inc.
1140 Railroad Street
P. O. Box 753
Paso Robles, California
93446

(2) El Paso Natural Gas Co.,
Mining Division
P. O. Box 627
Weiser, Idaho 83672

(3) New Idria Mining and
Chemical Company
21731 Almaden Road
San Jose, California
95120

(4) New Idria Mining and
Chemical Company
Idria Mine
Idria, California 95027

(5) New Idria Mining and
Chemical Company
New Almaden Mine
P. O. Box 68
Almaden, California 95042

(6) New Idria Mining and
Chemical Company
Old Guadalupe Mine
18501 Hicks Road
Los Gatos, California
95120

(7) Superior Gypsum Company
2150 Franklin Street
Oakland, California
94612

(8) Superior Gypsum Company
Petaluma Mine
Petaluma, California 94952

Molybdenum Ore Processing Companies

(1) Climax Molybdenum Company
Div., AMAX
Western Operations Hqs.
Mines Park
Golden, Colorado 80401

(2) Climax Molybdenum Company
Climax Mine
Climax, Colorado 80429

(3) Climax Molybdenum Company
Henderson Mine
P. O. Box 63 (Georgetown)
Empire, Colorado 80438

(4) Molybdenum Corporation of America
Questa Mine
Questa, New Mexico 87556

Nickel Ore Producers

(1) The Hanna Mining Company and
  The Hanna Nickel Smelting Company
 Riddle, Oregon 97469

Platinum Concentrate Producers

(1) Goodnews Bay Mining Company
Platinum
Alaska 99651

(2) United States Platinum Milling, Incorporated
P. O. Box 481
Bridgeport, California 93517

Rare Earth Metals Ore Producers

(1) Curtis Nevada Mills, Inc.
P. O. Box 133
Rickey Canyon, California

(2) Molybdenum Corporation of America
Nipton
California 92366

Silver Ore Processing Companies

(1) American Smelting and Refining Company
Galena Unit
P. O. Box 440
Wallace, Idaho 83873

(2) Black & White Mining Co.
4207 21st Avenue
Missoula, Montana 59801

(3) Black & White Mining Company
Brooklyn Mine
Maxville, Montana 59801

(4) Bunker Hill Company
Crescent Mine
P. O. Box 29
Kellogg, Idaho 83837

(5) Clayton Silver Mines
P. O. Box 890
Wallace, Idaho 83873

(6) Hecla Mining Company
Consolidated Silver Project
P. O. Box 259
Osburn, Idaho 83849

(7) Hecla Mining Company
Lucky Friday Mine
Mullan, Idaho 83846

(8) Homestake Mining Company
Bulldog Mountain Project
P. O. Box 98
Creede, Colorado 81130

(9) McFarland & Hullinger
915 North Main Street
Tooele, Utah 84074

(10) McFarland & Hullinger
Ophir Mine
Ophir, Utah 84056

(11) Minerals Engineering Company
Creede Associates, Ltd.
P. O. Box 377
Creede, Colorado 81130

(12) Montecito Minerals Company
1482 East Valley Road
Santa Barbara, California
93108

(13) Nancy Lee Mines, Inc.
P. O. Box 67
Kellogg, Idaho 83837

(14) Sierra Silver Lead Mining Co.
46 East Thirtieth Avenue
Spokane, Washington 99203

(15) Standard Resources, Inc.
P. O. Box 1106
Carson City, Nevada 89701

(16) Sunshine Mining Company
Sunshine Mine
P. O. Box 1080
Kellogg, Idaho 83837

(17) Sunshine Mining Company
Sixteen-to-One Mine
Silver Peak, Nevada 89047

(18) Universal Exploration, Inc.
Silver Moon Mine
3935 North Yellowstone
Idaho Falls, Idaho 83401

Thorium Ore Producers

(1) E. I. du Pont de Nemours
& Company, Inc.
(Clay County) Florida

(2) Humphreys Mining Company
(Charlton County) Georgia

(3) Titanium Enterprises, Inc.
(Clay County) Florida

(4) Climax Molybdenum Company
Leadville
Colorado

(5) Kendrick Bay Mining Company
Prince of Wales Island County
Alaska

Raw Materials

The occurrence of thorium is widespread, and large deposits are found in beach and fluviatile placers, veins, sedimentary rocks, alkalic igneous rocks, and carbonatites. The principal minerals recovered for thorium extraction are monazite, $(Ce,La,Th)PO_4$; thorite, $ThSiO_4$; multiple oxide minerals of Ti,U,Ca,Fe,Th, and Y, such as brannerite; and thorianite, ThO_2. Important thorium contents are present in some uranium ores but not in most of the U. S. uranium ores. The amount of thorium present in our stateside uranium ores is generally too small for economic recovery. An Alaskan uranium mine does recover thorium as a by-product, however. Thus, the domestic source for thorium is principally monazite as previously described--a by-product in titanium and molybdenum ore recovery operations. While the ThO_2 content of monazite may range between 0 and 32 percent, the domestic monazite contains from about 3.5 to 9 percent ThO_2, with a 5 percent average over several years from all production.

Thorium Ore Products

Monazite concentrates (imported concentrates are processed as well as domestically produced concentrates) are treated chemically to recover the rare earth-oxide content. In the chemical plants, thorium phosphate precipitate is recovered in one process. Another process results in a hydroxide residue. These compounds can be purified by solvent extraction techniques and ultimately high purity thorium nitrate, thorium oxide, or other thorium compounds can be obtained chemically. Metallic thorium can be produced by reduction of the halides with calcium or magnesium, fused-salt electrolysis, or by other methods, all of which require a high technology for the production of pure metal.

Tin Concentrate Producers

(1) Climax Molybdenum Company
Division of AMAX
Western Operations Hqs.
Mines Park
Golden, Colorado 80401

(2) Climax Molybdenum Company
Climax Mine
Climax, Colorado 80429

Raw Materials

The tin-containing mineral of worldwide economic importance is cassiterite, SnO_2.

Tin Products

A small amount of tin reports along with the tungsten and other non-molybdenum minerals in the tailings from the molybdenum mining operations in Colorado. These non-molybdenum minerals are concentrated and separated from one another in a gravity-flotation process. The tin mineral concentrate is finally separated from tungsten concentrate by magnetic separation as indicated in the flow diagram for molybdenum.

Titanium Ore Processing Companies

(1) American Smelting and
Refining Company
Oak Tree Road and
Park Avenue
South Plainfield,
New Jersey 07080

(2) E. I. du Pont de Nemours
& Company, Inc.
Highland Plant
P. O. Box 68
Lawtey, Florida 32092

(3) E. I. du Pont de Nemours
& Company, Inc.
Trail Ridge Plant
P. O. Box 753
Starke, Florida 32091

(4) The Feldspar Corporation
P. O. Box 69
Middletown, Connecticut
06458

(5) Glidden-Durkee Division
SCM Corporation
P. O. Box 5
Lakehurst, New Jersey
08733

(6) National Lead Industries,
Incorporated
111 Broadway
New York, New York 10006

(7) The Feldspar Corporation
Rt. 1, P. O. Box 23
Montpelier, Virginia
23192

(8) Humphreys Mining Company
P. O. Box 8
Folkston, Georgia 31537

(9) Titanium Enterprises, Inc.
Green Cove Springs
Florida

Tungsten Ore Processing Companies

(1) Comeback Consolidated Inc.
Placerville
California

(2) Henry C. & John Crofoot
P. O. Box 797
Lovelock, Nevada 89419

(3) General Electric Company
Minerals Engineering Company
Dillon, Montana

(4) General Electric Company
Minerals Engineering Company
Avron, Montana

(5) General Electric Company
Minerals Engineering Company
White Pine County, Nevada

(6) Las Maderas Mining and
Petroleum, Ltd.
Fresno
California

(7) Mines Exploration, Inc.
P. O. Box 27
Red Mountain, California
92374

(8) Montecito Minerals Company
1482 East Valley Road
Santa Barbara, California
93108

(9) Montecito Minerals Company
P. O. Box 125
Darwin, California 93522

(10) Frank Ramsey
3445 Court Street
Baker, Oregon 97814

(11) Rawhide Mining Company
Rawhide
Nevada

(12) Tungsten Properties, Ltd.
P. O. Box A
Imlay, Nevada 98418

(13) Union Carbide Corporation
Mining & Metals Division
270 Park Avenue
New York, New York 10017

(14) Union Carbide Corporation
Pine Creek Mine and Mill
Bishop, California 93514

Uranium Ore Producers

(1) Altamont Uranium and
Mining Company, Inc.
P. O. Box 1776
Salt Lake City, Utah
84110

(2) The Anaconda Company
Jackpile-Paguate Mine
P. O. Box 638
Grants, New Mexico 87020

(3) Atlas Minerals Division
Atlas Corporation
Big Indian Mines
P. O. Box 1207
Moab, Utah 84532

(4) Atlas Minerals Division
Atlas Corporation
Moab Mill
P. O. Box 1207
Moab, Utah 84532

(5) Blake Mining Company
Box 431
Nucla, Colorado 81424

(6) Continental Oil Co., Inc.
Conquista Project
P. O. Box 300
Falls City, Texas 78113

(7) Continental Uranium Company
of Wyoming
Box 662
Oracle, Arizona 85623

(8) Dawn Mining Company
P. O. Box 25
Ford, Washington 99013

(9) Exxon Company, USA
Exxon Corporation
P. O. Box 3020
Casper, Wyoming 82601

(10) Exxon Company, USA
P. O. Box 2180
Houston, Texas 77001

(11) Federal-American Partners
520 East Main
Riverton, Wyoming 82501

(12) Four Corners Exploration Co.
Box 116
Grants, New Mexico 87020

(13) Homestake Mining Company
P. O. Box 77
Grants, New Mexico 87020

(14) Kendrick Bay Mining Company
Prince of Wales Island County
Alaska

(15) Kerr-McGee Corporation
P. O. Box 218
Grants, New Mexico

(16) Kerr-McGee Corporation
P. O. Box 2855
Casper, Wyoming 82601

(17) Mines Development, Inc.
P. O. Box 49
Edgemont, South Dakota 57735

(18) Mountain West Mines, Inc.
P. O. Box 126
Blanding, Utah 84511

(19) Petrotomics Company &
KGS--JV
P. O. Drawer 2459
Casper, Wyoming 82601

(20) Ranchers Exploration &
Development Corporation
1776 Montano Road, N.W.
Albuquerque, New Mexico
87107

(21) Ranchers Exploration &
Development Corporation
P. O. Box 2787
Grants, New Mexico 87020

(22) Rio Algom Corporation
P. O. Box 610
Moab, Utah 84532

(23) Susquehanna Western, Inc.
Box 217
Falls City, Texas 78113

(24) Operations #2
Box 767
Three Rivers, Texas 78071

(25) Union Carbide Corporation
Mining & Metals Division
Grand Junction, Colorado
81501

(26) Union Carbide
Rifle Plant
Box 832
Rifle, Colorado 81650

(27) Union Carbide
Uravan Plant
Uravan, Colorado 81346

(28) Union Carbide Corporation
Mining & Metals Division
Gas Hills Station
Box 1500
Riverton, Wyoming 82501

(29) United Nuclear Corporation
Mining & Milling Division
P. O. Box 3951
Albuquerque, New Mexico 87110

(30) United Nuclear Corporation
Ambrosia Lake Operation
P. O. Box 199
Grants, New Mexico 87020

(31) United Nuclear-Homestake
Partners
P. O. Box 98
Grants, New Mexico 87020

(32) Utah International, Inc.
Shirley Basin Mine
Shirley Basin, Wyoming 82061

(33) Utah International, Inc.
Lucky Mc Mine
P. O. Box 831
Riverton, Wyoming 82501

(34) Western Nuclear, Inc.
Jeffrey City Operations
Jeffrey City, Wyoming 82219

(35) Western Nuclear, Inc.
Rox Operations
254 North Center Street
Casper, Wyoming

Vanadium Ore Producers

(1) Union Carbide Corporation
Route 6
P. O. Box 943
Hot Springs, Arkansas 71901

(2) Kerr-McGee Chemical Corporation
Soda Springs Plant
P. O. Box 478
Soda Springs, Idaho 83276

Zirconium Ore Producers

(1) E. I. du Pont de Nemours
& Company, Inc.
Highland Plant
P. O. Box 68
Lawtey, Florida 32092

(2) E. I. du Pont de Nemours
& Company, Inc.
Trail Ridge Plant
P. O. Box 753
Starke, Florida 32091

(3) Humphreys Mining Company
Folkston Plant
P. O. Box 8
Folkston, Georgia 31537

(4) Titanium Enterprises, Inc.
Green Cove Springs
Florida

Raw Materials

Both of the principal zirconium minerals, zircon ($ZrSiO_4$) and baddeleyite (ZrO_2), occur as primary constituents in alkaline-rich igneous rocks. The occurrence of these minerals in this mode is widespread but there are no richly concentrated igneous rock deposits of either mineral known in the U. S. The anciently formed placer deposits along the Eastern seacoast, derived from igneous rock masses, contain much more zircon than baddeleyite and are the only current source of zirconium ore in the U. S.

Zirconium Products

The product resulting from the U. S. mining and beneficiating of ores containing zirconium minerals is zircon concentrate, a by-product from titanium mineral production.

APPENDIX B

Raw Materials, Minerals, and Products Utilized in Metal-Mining and Milling Industry

TABLE 1. UNITED STATES METAL-MINING INDUSTRY: METALS, RAW MATERIALS, MINERALS, AND PRODUCTS

(MAJOR GROUP 10, SIC)

			Mining and Beneficiating Materials			Produced as
			Raw Materials			a. Principal b. Coproduct c. By-Product
Metal	Chemical Symbol	SIC No.	Ore Deposit Name	Principal Mineral(s)	Beneficiated Product(s), Names	
Aluminum	Al	1051	High-Grade Bauxite Deposit	Bauxite	Metallurgical Grade Bauxite	a
			Low-Grade Bauxite Deposit		Nonmetallurgical Grade Bauxite	
Antimony	Sb	1099	Stibnite Content Deposit	Stibnite	High-Grade Ore Concentrate	a, b, c
					Medium-Grade Ore Concentrate	
Beryllium	Be	1099	Pegmatitic Ore Body	Beryl	Beryl Concentrate	a
			Bertrandite Ore Body	Bertrandite	$BeSO_4$ Filtrate	
Columbium (Niobium)	Cb (Nb)	1061	Rare Earth Complex Deposit	Columbite	Columbite Concentrate	c
Copper	Cu	1021	High-Grade Ore Deposit	Chalcocite	High-Grade Ore Concentrate	a, b, c
			Low-to-High Grade Ore Deposit	Chalcopyrite	Filter Cake	
			Very low Grade Ore Deposit	Cuprite	Native Copper Concentrate	
				Malachite	Cement Copper	
				Native Copper	Cement Copper Concentrate	
				Azurite	Concentrated Copper Solution	
Gold	Au	1041	Placer Gold Deposit	Native Gold	Rich Gold Ore Concentrate	a, b, c
			Lode Gold Deposit		Gold Amalgam	
					Crude Gold Bullion	
					Concentrated Gold Solution	
					"Black" Powder, Gold Precipitate	
Iron	Fe	1011	Magnetite Ore Body	Magnetite	Run of Mine Ore	a, b, c
			Magnetite-Hematite Ore Body	Hematite	Direct Shipping Ore	
			Hematite Ore Body	Pyrite	Iron Ore Concentrate	
			Hematite-Limonite Ore Body	Siderite	Mangainferous Iron Ore Concentrate	
			Iron Pyrites Ore Body	Limonite	Iron Ore Sinter	
			Manganiferous Iron Ore Body		Iron Ore Briquettes	
			Limonite-Siderite Ore Body		Iron Ore Pellets	
			Jaspilite Ore Body		Iron Ore Nodules	
			Taconite Ore Body			
Lead	Pb	1031	Lead Ore Deposit	Galena	Lead Concentrate	a, b, c
			Lead-Zinc Ore Deposit	Cerrusite		
Manganese	Mn	1061	Iron-Manganese Deposit	Manganite	High Manganese Content Iron Ore	c
			Zinc Ore Deposit	Pyrolusite	Manganese in Residue	

TABLE 1: (Continued)

Metal	Chemical Symbol	SIC No.	Mining and Beneficiating Materials: Raw Materials: Ore Deposit Name	Mining and Beneficiating Materials: Raw Materials: Principal Mineral(s)	Mining and Beneficiating Materials: Beneficiated Product(s), Names	Produced as a. Principal b. Coproduct c. By-Product
Mercury	Hg	1092	Cinnabar Content Deposit	Cinnabar	Cinnabar Ore Concentrate Mercury (Metal)	a, c
Molybdenum	Mo	1061	Molybdenum Content Deposit	Molybdenite	Molybdenite Concentrate	a, b, c
Nickel	Ni	1061	Nickel Content Garnierite Deposit	Garnierite	Ferronickel Alloy (Metal)	a
Platinum(a)*	Pt	1099	Platinum Content Placer Deposit	Native Pt-Group Metals	Platinum Content Concentrate	a, b, c
Radium	Ra	1094	Uranium Content Deposit	Uraninite	Not recovered as a product	-
Rare Earths(b)*	RE	1099	Bastnäsite Deposit Rare-Earth Complex Deposit	Bastnäsite	Rare-Earth Concentrate	a, c
Silver	Ag	1044	Silver Complex Deposit Silver-Gold Deposit	Tetrahedrite Electra	Silver-Base-Metal Concentrate Silver-Gold Solution	a, b, c
Tantalum	Ta	1061	Rare-Earth Complex Deposit	Tantalite	Tantalite Concentrate	c
Thorium	Th	1099	Titania Placer Deposit Molybdenum Content Deposit	Monazite	Monazite Concentrate(c)*	c
Titanium	Ti	1099	Titania Placer Deposit Titania-Nonmetal Lode Deposit Titania-Magnetite Deposit	Ilmenite Rutile Leucoxene	Rutile Concentrate Ilmenite Concentrate Rich Titania Content Concentrate Lean Titania Concentrate	a, b
Tin	Sn	1099	Molybdenum Content Deposit	Cassiterite	Nonmagnetic Tin Concentrate	c
Tungsten	W	1061	Scheelite Content Deposit	Scheelite	Scheelite Concentrate Ammonium Paratungstate	a, b, c
Uranium	U	1094	Uranium Content Deposit	Uraninite Thucholite	Yellow Cake	a, b
Vanadium	V	1094	Complex Vanadium Minerals Deposit	Carnotite Montroseite Fervanite	Technical Grade V_2O_5 Ammonium Metavanadate Pure Vanadium Pentoxide	a, b, c

* Footnotes on next page.

TABLE 1: (Continued)

			Mining and Beneficiating Materials			Produced as
			Raw Materials			a. Principal b. Coproduct c. By-Product
Metal	Chemical Symbol	SIC No.	Ore Deposit Name	Principal Mineral(s)	Beneficiated Product(s), Names	
Zinc	Zn	1031	Zinc Ore Deposit Zinc-Lead Ore Deposit	Sphalerite Calamine	Zinc Concentrate	a, b, c
Zirconium	Zr	1099	Titania Placer Deposit	Zircon	Zircon Concentrate	c

(a) Category includes all of the Platinum-Group Metals: platinum (Pt) palladium (Pd) iridium (Ir) osmium (Os) rhodium (Rh) and ruthenium, Ru.

(b) Category includes all of the Rare-Earth Metals: cerium (Ce) dysprosium (Dy) erbium (Er) europium (Eu) gadolinium (Gd) holmium (Ho) lanthanum (La) lutetium (Lu) neodymium (Nd) praseodynium (Pr) promethium (Pm) samarium (Sm) terbium (Tb) thulium (Tm) and ytterbium (Yb). In addition, some commercial groups choose to include yttrium (Y) and scandium (SC) in the rare-earths group.

(c) Thorium is recovered as a by-product during the recovery of rare-earth oxides and metals from monazite. Monazite is itself a by-product from titanium and molybdenum mineral recovery operations.

TABLE 2. RAW MATERIALS UTILIZED IN THE MINING AND BENEFICIATING OF METALLIC ORES (Examples)

Process	Process Step	Materials and Remarks
Mining	Ore Body Conditioning	Explosives (fuel oil as explosives extender) Fuels and lubricants (e.g., for drilling equipment)
	Ore digging & loading	Fuels and lubricants (for equipment operation) Wooden timbers (for mine support or ore-gangue separation) Steel (chain link fence and rods for mine support. Elevator and building construction)
	Transportation	Fuels and lubricants (tire rubber is significant)
Beneficiation	Crushing & Grinding	Fuels and lubricants (for operating equipment) Steel [balls & liners] (1.5 pounds per ton of ore) Water (4 tons per ton of ore--added in grinding, carried through to pulp dewatering, mostly recycled)
	Classifying, Washing	Fuels & lubricants (for operating equipment) Lime (conditioner, e.g., pH modifier) Zinc sulfate (conditioner 0.1 pounds per ton of ore) Sodium sulfide (depressent 0.08 pounds per ton of ore) Sodium cyanide (depressent 0.005 pounds per ton of ore)
	Flotation (e.g. MoS_2)	1,1,3 Triethoxy butane (0.05 pounds per ton of ore) Zanthate ester (0.007 pounds per ton of ore) "N" Silicate (0.20 pounds per ton of ore) Phosphorus pentasulfide (0.06 pounds per ton of ore) Potassium permanganate (0.003 pounds per ton of ore) Polyacrylamid [water soluble] (0.008 pounds per ton of ore)
	Leaching	Sulfuric acid (e.g. copper leaching) Sodium cyanide (e.g. gold leaching)